11/28/62

Tw-5

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TECHNICAL LETTER: NTS-34

SUMMARY OF HYDRAULIC TESTS AND ABRIDGED LITHOLOGIC LOG FOR GROUND-WATER TEST WELL 5, NYE COUNTY, NEVADA

By

Lewis R. West and Murray S. Garber

November 28, 1962

These data are preliminary and should not be quoted without permission.

Prepared by the Geological Survey for the U. S. Atomic Energy Commission.

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Technical Letter
NTS-34
November 28, 1962

Federal Center, Denver 25, Colorado

Mr. James E. Reeves, Manager
Nevada Operations Office
U. S. Atomic Energy Commission
P. O. Box 1676
Las Vegas, Nevada

Dear Mr. Reeves:

Transmitted herewith are two copies of:

TECHNICAL LETTER: NTS-34

SUMMARY OF HYDRAULIC TESTS AND ABRIDGED
LITHOLOGIC LOG FOR GROUND-WATER TEST WELL 5,
NYE COUNTY, NEVADA

By

Lewis R. West and Murray S. Garber

November 28, 1962

Additional copies have been distributed as indicated below.

Sincerely yours,

F N Houser

F. N. Houser
Program Supervisor
Nevada Test Site

Enclosures (2)
Distribution:
- Technical Library, NVOO (4)
- DTIE, Oak Ridge, Tenn. (1)
- A. Clebsch, AEC, Wash. (5)
- J. F. Philip, SAN (1)
- Cdr. H. E. Stephens DMA (1)
- Roland F. Beers, Inc. (14)
- Hazleton Nuclear Sci. Corp. (3)
- Holmes & Narver, Inc. (1)
- N. Short, LRL (1)
- W. Richards, LRL (1)
- W. E. Cordek, Sandia (2)
- W. Helterbran, Hq. USAF/AFTAC (1)
- G. Debuchannane (1)
- P. H. Jones (1)
- I. Winograd (12)
- Sample Data Center (5)
- J. R. Henderson (1)
- S. L. Schoff (2)
- V. E. McKelvey (1)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Technical Letter
NTS-34
November 28, 1962

Federal Center, Denver 25 Colorado

SUMMARY OF HYDRAULIC TESTS AND ABRIDGED LITHOLOGIC LOG FOR GROUND-WATER TEST WELL 5, NYE COUNTY, NEVADA

By

Lewis R. West and Murray S. Garber

This technical letter summarizes data obtained from the drilling of ground-water test well 5. It discusses the well construction, presents a lithologic log of the formations penetrated, and gives the results of two hydraulic tests made in the well.

Test well 5 is one of several wells drilled to explore geologic and hydrologic conditions at the Nevada Test Site; it is part of the Long Range Program of the Geological Survey, which is being carried out in behalf of the Atomic Energy Commission. The well was drilled by the Western Republic Drilling Co., Lubbock, Tex., under contract to the U.S. Atomic Energy Commission. Contract administration and inspection were provided by engineers of Holmes and Narver, Inc., Los Angeles, Calif.

Test well 5 is about 5 miles east of Lathrop Wells, Nev., and 1 mile north of U.S. Highway 95 (fig. 1), and is at Nevada State coordinates N 687,231 and E 607,632 (central zone). The altitude of the land surface at the well site is 3,053 feet.

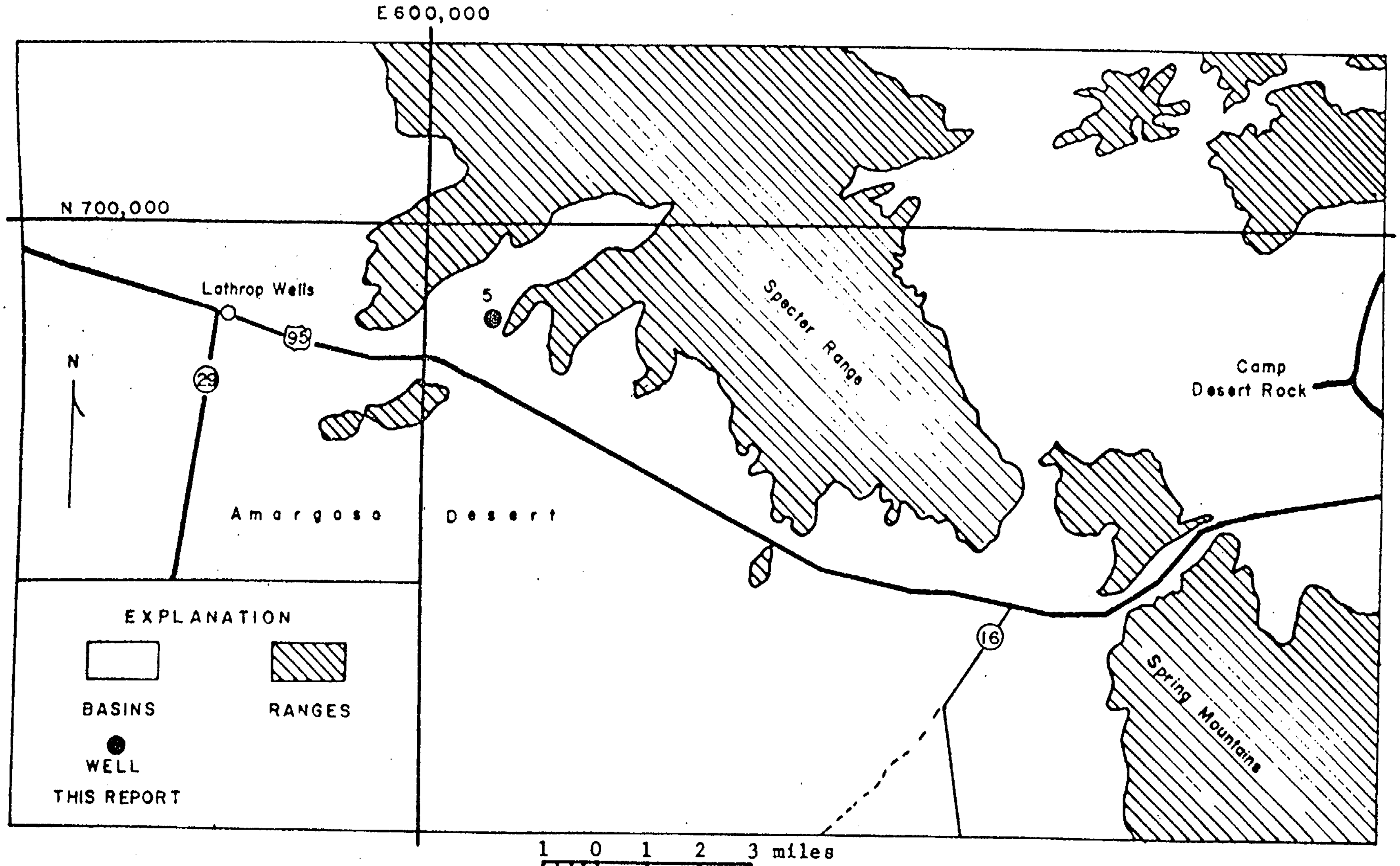


Figure 1. Sketch map showing location of ground water test well 5, Nye County, Nevada

Work on the well began June 22 and ended July 9, 1962. The well was drilled with a rotary-drilling machine using air and mud alternately as the drilling fluids. The proposed depth was 1,500 feet, but adverse drilling conditions necessitated termination of drilling at 916 feet below land surface.

The well is cased from 0 to 166 feet with 13 5/8-inch OD (outside diameter) casing and from 0 to 800 feet with 7-inch OD casing. The lower 65 feet of the 7-inch casing is machine-slotted. A summary of the casing and cementing of the well is given in table I.

The hole began to cave in the interval below 815 feet when it was 916 feet deep. On several occasions the drill string was stuck for periods of several hours. In an attempt to stop the caving the drilling fluid was changed from air to mud, but caving of the bore continued. The drilling operation therefore was stopped at a depth of 916 feet. The hole then was reamed, with air as the drilling fluid, to a depth of 800 feet. It was then logged geophysically, and the second string of casing was installed. It is presumed that the hole below the bottom of the casing is filled with cuttings or cavings.

The well penetrated 160 feet of alluvium of Quaternary and possibly Tertiary age, and 756 feet of sedimentary strata of Paleozoic age. The alluvium consists principally of limestone and dolomite detritus. The Paleozoic strata consist of limestone, dolomite, shale, and argillite tentatively identified as part of the Carrara Formation of Cambrian System. An abridged lithologic log of the formations penetrated in the well is given in table 2.

The static water level in test well 5 is about 675 feet below land surface (altitude 2,378 feet). The interbedded limestone, argillite, and shale penetrated yielded small quantities of water to the well. The hydraulic properties of these strata were tested once by swabbing and once by bailing. The swabbing test was made prior to the utilization of mud in the drilling operation, when the hole was 856 feet deep. The bailing test was made after the hole had been cased. In these tests the bore was swabbed or bailed dry. Measurements of the rate of fluid recovery in the bore indicate that the yield of the strata is less than 5 gallons per minute.

The casing was left in the hole and was capped so that the well may be used for future observations of water level.

A water sample for chemical analysis was not collected because considerable quantities of drilling mud and other materials had been put into the hole during the drilling by the rotary-hydraulic method. Only a small part of these materials was removed by swabbing and bailing, and a water sample would not have represented the natural water of the strata.

Table 1.--Casing and cementing record of test well 5

All casing is seamless steel, thread type, 8 round, with API short couplings. The 13 3/8-inch casing has a 1/2-inch wall and weighs 40 pounds per linear foot. The 7-inch casing has a 3/8-inch wall and weighs 20 pounds per linear foot.

Table 1.--Casing and cementing record of test well 5--Continued

Interval (feet)	Casing and cementing
0 - 166	13 3/8-inch OD casing with a Halliburton open-guide shoe screwed to bottom of lower joint. All joints locked with electric weld. Casing cemented from surface to bottom by Halliburton with 50-50 Pozmix A with 2 percent HA-5.
0 - 735	7-inch OD blank casing.
735 - 800	7-inch OD casing with machine-cut vertical slots; slots are 0.125-inch wide by 2 inches long, on 6-inch centers, and in staggered rows so that alternate rows are aligned; the bottom joint is "orange peeled" forming a "bull-nose" plug.

Table 2.--Abridged lithologic log for hydrologic test well 5

	Interval (feet)	Depth (feet)
Alluvium composed largely of fragments of limestone and dolomite with lesser amounts of sandy limestone plus trace amounts of clayey-crystal tuff; limestone fragments olive gray, dolomite dark bluish-gray to black, and sandy limestone yellowish-brown	160	160

Table 2.--Abridged lithologic log for hydrologic test well 5--Continued

	Interval (feet)	Depth (feet)
Limestone; medium to dark gray, fine-grained, contains numerous mineralized veinlets; vein material lighter in color than host rock, pinkish-gray to white and finely crystalline; thin bands of tan sandy limestone	240	400
Sandy limestone and argillite interbedded; argillite, olive gray, thin-bedded and micaceous; sandy limestone pinkish-gray to tan, sand fine- to medium-grained, limestone finely crystalline; trace amounts of dolomite below 500 feet	170	570
Sandy shale; olive tan, with fine-grained sand; trace amounts of limestone, dark gray, medium crystalline	20	590
Shale as above, but with as much as 30 percent limestone	70	660
Sandy limestone and calcareous sandstone; sandy limestone pale greenish-gray, contains fine- to medium-grained sand particles in a finely crystalline matrix; calcareous sandstone pale pink, consists of medium-grained sand		

Table 2.--Abridged lithologic log for hydrologic test well 5--Continued

	Interval (feet)	Depth (feet)
particles in a finely crystalline cement	40	700
Same as above, but contains greenish argillite in trace amounts	40	740
Argillite; pinkish-gray, with about 15 percent dolomite; argillite dark greenish-gray, medium crystalline	60	800
Dolomite, light gray, finely crystalline; and shale, dark gray, about 40 percent	20	820
Shale and shaly limestone, interbedded; shale medium to dark gray; shaly limestone light gray and bluish-gray, fine-grained; about 30 percent argillite, brownish-gray and pale orange..	90	910

1/30/98

DRAFT DISCLAIMER

BERKELEY LAB

Earth Sciences Division

January 30, 1998 QA:N/A

Larry R. Hayes
Scientific Programs Operations
1180 Town Center Drive
MS 423/1265
Las Vegas, Nevada 89134

WBS: 1.2.3.11.2

ATTN. Terry A. Grant, Planning and Performance

SUBJECT: In accordance with YAP 5.1Q, this report fulfills Level 4 Milestone SP3B6DM4: "Results of Gravity Modeling of the Paleozoic Basement."

Enclosed, please find a copy of the above milestone entitled "Results of Gravity Modeling of the Paleozoic Basement" by E.L. Majer, L. Johnson, D.W. Vasco, and P. Parker. This report fulfills Level 4 Milestone SP3B6DM4 which summarizes gravity modeling of the paleozoic basement.

Per YMP-LBNL-QIP 6.1, technical reviews were performed by R. Gritto and M. Fieghner, and a quality assurance review was performed by D. Mangold. Since no technical data have resulted from this deliverable, a technical data information form is not included in this submittal. Also included as part of this submittal is a Milestone Criteria Table which explains how the different parts of the criteria statement are met.

Sincerely,

Gudmundur S. Bodvarsson
Head, Nuclear Waste Department
Earth Science Division

Enclosure

cc: E.L. Majer
RPC

Ernest Orlando Lawrence Berkeley National Laboratory
One Cyclotron Road | Berkeley, California 94720 | Tel: 510.486.7071 | Fax: 510.486.5686

Deliverable Data

ID: 295 **Deliverable ID:** SP3B6DM4 **Participant:** LBNL **Milestone Level:** 4 **Type:**

Deliverable Title: Rpt: Results of Gravity Mdlng Palozoc Bsmnt

Control Account ID: 123B2210 **Control Account Title:** Geophysics Support

Work Package ID: M1 **Work Package Title:** Geophysical Data Evaluation

Product ID: 2210 **Product Title:** ST23E - Geologic Testing for LA

WBS: 1.2.3.11 **MO Manager:** Biggar **DOE Manager:** Yasek

Baseline Due Date: 1/30/98 **Actual Completion:** 2/4/98

Description:

This milestone will be satisfied by the submittal to the CRWMS M&O Scientific Programs Operations Manager of a completed letter report that has undergone formal review in accordance with the CRWMS M&OM Quality Assurance program. A report describing the results of inverting the gravity daat with genetic based algorithms constrained by the results of the VSPn analysis will be produced. The primary result will be a Paleozoic surface for the 3-d model. Also used in the constraints will be a reinterpretation of the regional reflection data along line 3, based on the results of the VSP data in borehole UE-25 p#1. The data will be submitted to the TDB in accrodance with Procedure AP-17.1Q.

Completion Criteria:

This deliverable is complete when 3 copies of the deliverable are submitted to the SPO Technical Lead for Reporting, Deliverables, & Data Compliance for M&O review and acceptance.

Acceptance Criteria:

Acceptance of the deliverable is determined by the M&O Work Package Manager through a review to determine if the deliverable meets all the elements in the deliverable description. Acceptance will also be contingent on receipt by the M&O Work Package Manager of evidence that any data cited or presented in the deliverable has been submitted to the Technical Data Management System through the GENISES database in accordance with Section 5.4 of YAP-SIII.3Q.

MQ Review Pending: ☑ **MQ Accepted:** ☐ **MQ Rejected:** ☐ **MQ Action Date:** 2/4/98

Date Sent to TPM: **Date Copy to DOE:**

DOE Accepted: ☐ **DOE Rejected:** ☐ **DOE Pended:** ☐ **DOE Action Date:**

Predecessor Deliverable:

Sucessor Deliverable:

Milestone Criteria Table

Milestone Title: Report: Results of Gravity Modeling of the Paleozoic Basement

Milestone No.: SP3B6DM4

Milestone Criteria	Section Where Criteria is Met
Results of gravity inversion	Section 8
Q status of the data and codes	Section 7
Comparison with reinterpretation of regional seismic line REG-3	Section 8

9/14/98

DRAFT DISCLAIMER

United States Department of the Interior

U. S. GEOLOGICAL SURVEY
Box 25046 M.S. 425
Denver Federal Center
Denver, Colorado 80225

IN REPLY REFER TO:

September 14, 1998

NON-QA
WBS:1.2.5.3.5

Phill Jones
GENISES Administrator
M&O/TRW
Yucca Mountain Project Office
1261 Town Center Drive
Las Vegas, NV 89134

SUBJECT: Geographic Nodal Information Study and Evaluation System (GENISES) Data Transmittal – **Water Chemistry Data from Samples Collected at Borehole USW WT-24, Between 10-6-97 to 12-10-97**

DTN: GS980108312322.005 TDIF: 306605 Category: 4 (Geochemical Characteristics)

The subject Data Transmittal Package is being submitted to the YMP GENISES in accordance with YMP Administrative Procedure (YAP)-SIII.3Q, Revision 2, ICN 0. All data have been technically reviewed as required. The following items are enclosed:

1. Technical Data Information Form, 2 p

2. Data Summary Sheet, 1 p.

3. Hard copy and Annotation pages with parameters and attributes, 7 p.

4. YMP-USGS Surrogate Record, 2 p.

5. One 3 1/2" diskette containing the subject data in ASCII format.

Please capture the annotated supporting information in GENISES. If you have any questions, please contact me at (303) 236-0516 x271, or Craig R. Walker at x278.

Sincerely,

Patrick W. McKinley

Patrick W. McKinley
Data Management Coordinator
Yucca Mountain Project Branch
U.S. Geological Survey

PWM: crw
Enclosures
Copy w/o enc. to: C.M. Newbury, DOE/YMP, Las Vegas
S.J. Bodnar, M&O/TRW, Las Vegas
R.W. Craig, USGS, Las Vegas
G. Patterson, USGS, Denver
K. Lewis, PWT, Denver
Copy w/ enc. to: Records Processing Center, Las Vegas, Items 3 & 4

YMP-USGS special instruction sheet
SURROGATE RECORD FOR TECHNICAL DATA

This surrogate record identifies non-paper media submitted as a data record.

Section 1 - Identification

Title: Water Chemistry Data from Samples Collected at Borehole USW WT-24, Between 10-6-97 and 12-10-97

Dates of coverage: 10-6-97 to 1-26-98

DTN(s):GS9801.8312322.005

Author(s): Patterson, G

Organization: USGS

Section 2 - Description of Medium

Number: 1 copy/copies of this record enclosed for record submittal
Each copy consists of 1 (*number of diskettes, tapes, etc., comprising one data set*):

Media/Format

■ DOS format diskette: Size: ☐ 5-1/4" ■ 3-1/2" *
Density: ■ 2-HD (double sided, high density) ☐ other (specify) ________

☐ Video tape: ☐ VHS ☐ other (specify) ________

☐ 8mm tape cassette*: Format: ☐ UNIX TAR ☐ other (specify) ________
Blocking factor: ☐ 20 ☐ other (specify) ________
Density: ☐ 2 GB ☐ other (specify) ________

☐ CD-ROM, ISO 9660 Standard

☐ 9-track tape: ☐ 6" ☐ 9" Format: ☐ UNIX TAR ☐ other (specify) ________
Density: ☐ 1600 BPI ☐ 6250 BPI Block Size: ________

☐ Other (describe) ________

*Acceptable for GENISES technical database submittal

Section 3 - For Project Records Use Only

ACCESSION NO.	ACCESS CONTROL CODE
TRACEABILITY DESIGNATOR	
COMMENTS:	

Section 4 - Hardware and Software requirements

System Hardware that can be used to read this file:

■ IBM and Compatibles ☐ Silicon Graphics ☐ Apple

☐ Digital/Dec ☐ Sun ☐ Data General

Other equipment (specify type and where it may be accessed: ______________________

File/Record Format ***(Check all that apply)*****:**

1. Type of files

■ ASCII files (control characters/software-specific characters stripped)*:

Record size: ■ CR/LF (carriage return/line feed) delimited records

☐ Fixed record length: _____, no record delimiter

☐ Other record delimiter (specify) ______________________

Field length: ■ Tab delimited fields ☐ Comma delimited fields ☐ Fields separated by spaces

☐ Other field delimiter (specify) ________ ☐ Description of fields and lengths attached.

Software used to generate ASCII files:

☐ Standard ASCII text editor (MS-DOS, UNIX VI, Norton, etc.)

☐ WordPerfect ☐ Paradox ☐ MS Word ■ Excel

☐ QuatroPro ☐ INGRES ☐ Lotus 1-2-3 ☐ dBase ☐ Framemaker

Other (specify): ______________________

☐ Binary files:

☐ Arc/Info export* ☐ AutoCad ..dxf* ☐ SEG-Y

☐ other standard file type (specify) ______________________

☐ Software-specific files - the following software is needed to read/print the files:

☐ WordPerfect ☐ Paradox ☐ MS Word ☐ Excel

☐ QuatroPro ☐ INGRES ☐ Lotus 1-2-3 ☐ dBase

Other (specify software and version, and accession number or location where it may be accessed):

____

Accceptable for GENISES technical database submittal.

2. Size and names of each file on media:

File Name	# Bytes	File Name	# Bytes
wt-24.txt	9,779	N/A	
N/A		N/A	
N/A		N/A	
N/A		N/A	
N/A		N/A	
N/A		N/A	
N/A		N/A	

Data Summary Sheet

Title: Water Chemistry Data from Samples Collected at Borehole WT-24, between 10-6-97 and 12-10-97.

Description of data:

Water chemistry data from samples collected at borehole WT-24 on Yucca Mountain, between 10-06-97 and 12-10-97. Data include analyses of tritium; stable isotope ratios for carbon-13, nitrogen-15, oxygen-18, and deuterium; total organic carbon; radon; physical parameters; and common anions and cations. Field parameters were measured by C. Savard and T. Oliver; the carbon-13, oxygen-18, and deuterium analyses were performed by R. Moscati; and the remaining analyses were done by the USGS National Water Quality Laboratory (NWQL). All sample ID numbers in this data package refer to borehole WT-24 water samples.

Intended use of data:

Physical and chemical parameters in groundwater can give indications of residence times and rock/water interactions. Analysis of stable isotopic abundance can assist in understanding flux through the mountain. From chemical and isotopic data, conceptual hydrologic flow at Yucca Mountain can be described.

Carbon isotopic data (Carbon-13/12) can help to identify carbon sources, a necessary step in C-14 age estimation. Carbon isotopic data can also provide information on flow mechanisms through Yucca Mountain as well as interactions with secondary calcite.

The detection of tritium in underground water may indicate the presence of pathways for water movement. Tritium in water indicates the presence of post-bomb water.

Comparisons of water collected at WT-24 to water collected at other boreholes in both saturated and perched water locations can help to determine the nature of the saturated layer intersected in borehole WT-24, and may provide evidence in understanding the steep water table gradient under this part of Yucca Mountain.

Accuracy requirements for the data:

No accuracy requirements are specified for chemistry data.

Actual accuracy of the data:

Accuracy in determining physical and chemical parameters is dependent on the detection levels of the instruments used for the analyses. The accuracy of analysis is considered adequate for the intended usage of the data, unless otherwise noted.

Known problems with the data:

There are no known problems with the data.

Software:

Lotus 123, Release 5, and QuattroPro were used to calculate the carbonate and bicarbonate ion concentrations. Excel 97 was used to tabulate the data and calculate the ion charge balances.

Data Manipulations

I) The charge balance was calculated using the following equation:

$$\text{Charge Balance} = \frac{100*(\text{cations}-\text{anions})}{(\text{cations}+\text{anions})}$$

where cations is the sum of milliequivalents of Ca, Mg, Na, and K
and anions is the sum of milliequivalents of Cl, SO4, F, NO3, HCO3, and CO3

II) Carbonate ion concentration was calculated as follows:

$$CO3 = \frac{N * 60.0092 * 10^3}{V_s} * V_1$$

where N = titrant normality
V_s = sample volume in ml
V_1 = volume of titrant added to first end-point, in ml

III) Bicarbonate ion concentration was calculated as follows:

$$HCO3 = \frac{N * 61.01712 * 10^3}{V_s} * (V_T - 2 * V_1)$$

where N = titrant normality
V_s = sample volume in ml
V_T = total volume of titrant added, in ml
V_1 = volume of titrant added to first end-point, in ml

SAMPLE COLLECTION INVENTORY						
USW WT-24		12/10/97		USGS 365301116271301		
SPC barcodes	collection date	collection time	bottle size	bottle type	sample treatment	parameter analysis and information
526802	12/10/97	14:45	1000ml	glass	RU	tritium
526803	12/10/97	14:45	1000 ml	glass	RU	tritium
526808	12/10/97	14:45	1000 ml	brown glass	FU	N-15
526809	12/10/97	14:45	1000 ml	brown glass	FU	N-15
526813	12/10/97	14:45	250 ml	poly	RU	physical parameters
526814	12/10/97	14:45	250 ml	poly	RU	physical parameters
526815	12/10/97	14:45	250 ml	poly	FA	cations
526816	12/10/97	14:45	250 ml	poly	FA	cations
526817	12/10/97	14:45	250 ml	poly	FU	anions
526818	12/10/97	14:45	250 ml	poly	FU	anions
526819	12/10/97	14:45	60 ml	glass	FU	stable isotopes
526820	12/10/97	14:45	60 ml	glass	FU	stable isotopes
526821	12/10/97	14:45	60 ml	glass	RU	TOC
526822	12/10/97	14:45	60 ml	glass	RU	TOC
526825	12/10/97	14:45	15 ml	vaccutainer	RU	C-13
526826	12/10/97	14:45	15 ml	vaccutainer	RU	C-13
526827	12/10/97	14:45	15 ml	vaccutainer	RU	C-13
526828	12/10/97	14:45	20 ml	vial	RU	radon
526829	12/10/97	14:45	20 ml	vial	RU	radon
9537	10/22/97	07:47	1000ml	glass	RU	tritium
9538	10/22/97	09:30	1000 ml	brown glass	FU	N-15
9539	10/22/97	07:50	250 ml	poly	RU	physical parameters
9541	10/22/97	08:50	250 ml	poly	FA	cations
9542	10/22/97	08:30	250 ml	poly	FU	anions
9545	10/22/97	08:56	120 ml	glass	FU	stable isotopes
9546	10/22/97	08:56	120 ml	glass	FU	stable isotopes
9547	10/22/97	07:50	120 ml	glass	RU	TOC
9548	10/22/97	08:30	15 ml	vaccutainer	RU	C-13
9549	10/22/97	08:30	15 ml	vaccutainer	RU	C-13
9550	10/22/97	07:50	120 ml	glass	RU	TOC
9551	10/22/97	07:50	250 ml	poly	RU	physical parameters
9552	10/22/97	08:30	250 ml	poly	FU	anions
9553	10/22/97	08:50	250 ml	poly	FA	cations
9554	10/22/97	09:30	1000 ml	brown glass	FU	N-15
9555	10/22/97	07:47	1000 ml	glass	RU	tritium
9556	10/22/97	07:50	20 ml	vial	RU	radon
9557	10/22/97	07:50	20 ml	vial	RU	radon
9574	10/06/97	14:00	250 ml	poly	RU	physical parameters
9575	10/06/97	14:00	250 ml	poly	RU	physical parameters
9576	10/06/97	14:00	250 ml	poly	FA	cations
9577	10/06/97	14:00	250 ml	poly	FA	cations
9578	10/06/97	14:00	250 ml	poly	FU	anions
9579	10/06/97	14:00	250 ml	poly	FU	anions
9580	10/06/97	14:00	120 ml	glass	FU	stable isotopes
9581	10/06/97	14:00	120 ml	glass	FU	stable isotopes

BLANKS INTENDED

YMP-USGS Technical Data Record

Subject/Title: Water Chemistry Data from Samples collected at Borehole USW WT-24, between 10/06/97 and 12/10/97.

Record date: 01/28/98

Author: G. L. Patterson **Organization:** USGS

Identifiers: Tritium, Carbon 13/12, Radon, Specific Conductance, Ca, Na, HCO3, NO3, PO4, Li, Sr, Ba, Cl, Cr, Cu, Pb, Ni, V, Isotopic Abundance, Total Organic Carbon-TOC, pH, Temperature, Mg, K, CO3, SO4, F, Br, Mn, SiO2, Be, Cd, Co, Fe, Mo, Ag, Zn, USW WT-24, Deuterium, NO2, Oxygen 18/16, Nitrogen 14/15

Traceability designators: SCP: 8.3.1.2.3.2.2
WBS: 1.2.3.3.1.3.2
DTN: GS980108312322.005

QA designator: QA:L

Data Record Authentication: Gary L Patterson **Date:** 1/28/98
G. L. Patterson, USGS

Approved for Release: [signature] **Date:** 8/24/98
for Chief Yucca Mountain Project Branch

Site Name	Date	Time	Temp	pH	Cond.	Charge	Ca	Mg	Na	K	Cl	SO_4	HCO_3	CO_3	NO_3	F	Br	SiO_2	TOC
			°C		µS/cm	Balance	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L as N	mg/L	mg/L	mg/L	mg/L
WT-24	971006	1400	25.2	8.3	331	-4.8	20	1.2	48	3.5	11.1	18	174*	–	–	1.3	0.56	43	–
WT-24	971022	900	22.9	8.1	296	4.3	24	1.5	39	2.5	9.1	15	135	0	0.37	0.8	0.11	46	0.5
WT-24	971022	915	22.9	8.1	296	-0.6	22	1.4	35	2.4	8.8	16	135	0	–	0.7	0.11	47	–
WT-24	971210	1445	–	8.6	276	11.7	18	1.3	39	2.9	–	–	121	6.2	–	–	–	35	0.4
WT-24	971210	1446	–	8.6	276	-3.5	18	1.2	36	2.9	8.9	16	121	6.2	–	0.8	0.96	38	–

* Lab alkalinity as HCO3

Site Name	Date	Time	NO_2	PO_4	Ba	Be	Cd	Cr	Co	Cu	Fe	Pb	Mn	Mo	Ni	Ag	Sr	V	Zn	Li
			mg/L as N	mg/L as P	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
WT-24	971006	1400	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	68.0
WT-24	971022	900	0.012	0.13	20	<0.5	<1.0	<5.0	6.2	<10	282	<10	128	17	<10	<1.0	169	<6.0	<3.0	27.1
WT-24	971022	915	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	25.2
WT-24	971210	1445	–	–	3	<1.0	<8.0	<14	<12	<10	11	<100	67.2	<60	<40	<4.0	128	<10	<20	46.6
WT-24	971210	1446	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	45.3

Site Name	Date	Time	^3H	δ^2H	$\delta^{18}O$	$\delta^{13}C$	^{222}Rn	$^{14}N/^{15}N$
			TU	permil	permil	permil	pCi/L	permil
WT-24	971006	1400	–	-100.0	-13.5	–	–	–
WT-24	971006	1400	–	-99.3	-13.2	–	–	–
WT-24	971022	900	<0.3	-99.5	-13.5	-11.7	760	5.6
WT-24	971022	900	–	-99.2	–	-12.1	–	–
WT-24	971022	900	–	–	–	-11.7	–	–
WT-24	971022	900	–	–	–	-11.8	–	–
WT-24	971210	1445	–	-102.2	-13.5	-10.7	601	–
WT-24	971210	1445	–	-99.0	-13.4	-10.8	–	–

BLANKS INTENDED

Conductivity Worksheet

Site Name : USW WT-24
Site ID : 365301116271301
Date : 10/22/97
Time : 900
Collected by : C. Savard

Meter : VWR A22066

Time	Name	Lot#	Meter
850	Plug	–	1000
855	504	97035	461
858	252	97029	231
859	98	97028	92.3
901	WT-24	–	275
903	WT-24	–	272 *
904	WT-24	–	271 *
905	WT-24	–	271 *

* Readings used for average

Average conductivity reading : 271.3333333

Corrected conductivity : 296

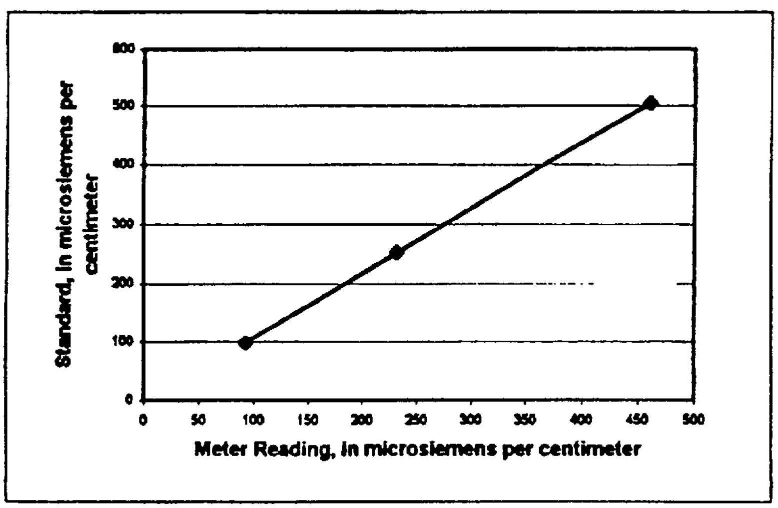
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999993747
R Square	0.999987493
Adjusted R S	0.999974986
Standard Erro	1.025090166
Observations	3

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	84017.61586	84017.61586	79955.10894	0.002251413
Residual	1	1.050809848	1.050809848		
Total	2	84018.66667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.06941754	1.177179542	-2.60743364	0.233141792	-18.0268377	11.88800265	-18.0268377	11.88800265
X Variable 1	1.100609783	0.003892335	282.7633444	0.002251413	1.051153184	1.150066382	1.051153184	1.150066382



Determination by : C Savard

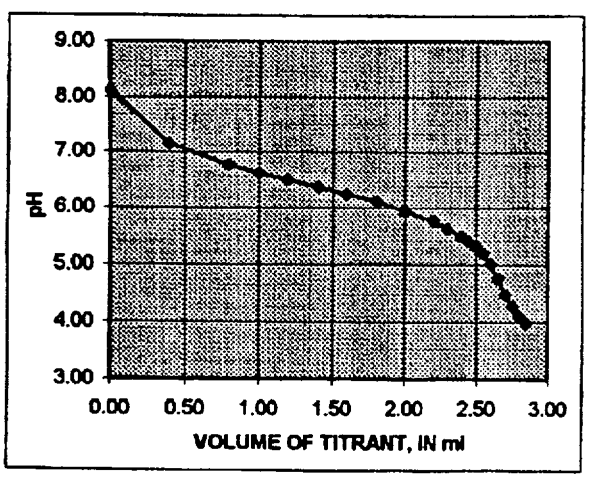
Date : 1/30/98

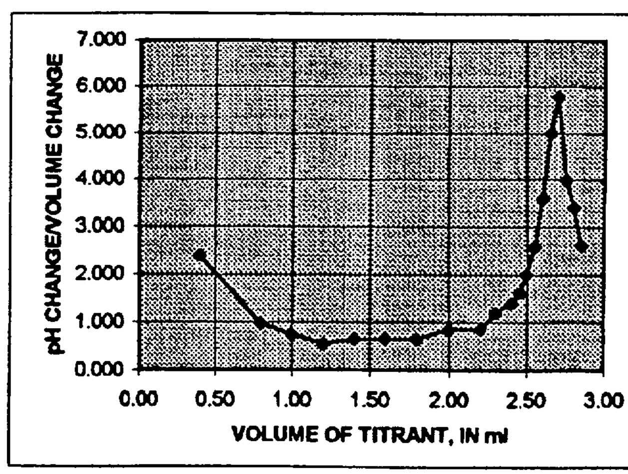
pH and Alkalinity Tritration

Site Name :	USW WT-24	pH :	8.11	CO3 endpoint (ml) :	0.00
Site ID :	365301116271301			CO3 (mg/L) =	0.00
SMF :				CO3 (meq/L) =	0.00
Date :	10/22/97	Sample volume (ml) :	20		
Time :		Titrant normality :	0.01639	HCO3 endpoint (ml) :	2.70
Collected by :	C. Savard			HCO3 (mg/L) =	135.01
		Meter No. :	233263	HCO3 (meq/L) =	2.21

Time	Sample	Lot No.	Meter Reading
917	7.0	955066-24	Adjust calibration knob to 7.0
918	4.0	964407-24	Adjust slope knob to 4.0
922	10.0	964975-24	10.02
925	WT-24	-	8.12
928	WT-24	-	8.11
929	WT-24	-	8.10
	Titration		
959	7.0	955066-24	7.02
1003	4.0	964407-24	4.02
1006	10.0	964975-24	10.05

Vol of titrant (ml)	pH	Change in vol.	Change in pH	pH change/ vol change
0.00	8.11			
0.40	7.15	0.40	0.96	2.400
0.80	6.76	0.40	0.39	0.975
1.00	6.61	0.20	0.15	0.750
1.20	6.50	0.20	0.11	0.550
1.40	6.37	0.20	0.13	0.650
1.60	6.24	0.20	0.13	0.650
1.80	6.11	0.20	0.13	0.650
2.00	5.94	0.20	0.17	0.850
2.20	5.77	0.20	0.17	0.850
2.30	5.65	0.10	0.12	1.200
2.40	5.51	0.10	0.14	1.400
2.45	5.43	0.05	0.08	1.600
2.50	5.33	0.05	0.10	2.000
2.55	5.20	0.05	0.13	2.600
2.60	5.02	0.05	0.18	3.600
2.65	4.77	0.05	0.25	5.000
2.70	4.48	0.05	0.29	5.800
2.75	4.28	0.05	0.20	4.000
2.80	4.11	0.05	0.17	3.400
2.85	3.98	0.05	0.13	2.600





Determination by : C Savard   Date : 1/30/98

Conductivity Worksheet

Site Name : USW WT-24
Site ID : 365301116271301
Date : 11/24/97
Time : 338
Collected by : C. Savard

Meter : VWR A22066

Time	Name	Lot#	Meter
330	Plug	–	1000
	98	97028	85
	252	97029	221
	504	97035	451
338	WT-24	–	274 *
339	WT-24	–	272 *
340	WT-24	–	272 *

* Readings used for average

Average conductivity reading : 272.6666667

Corrected conductivity : 307

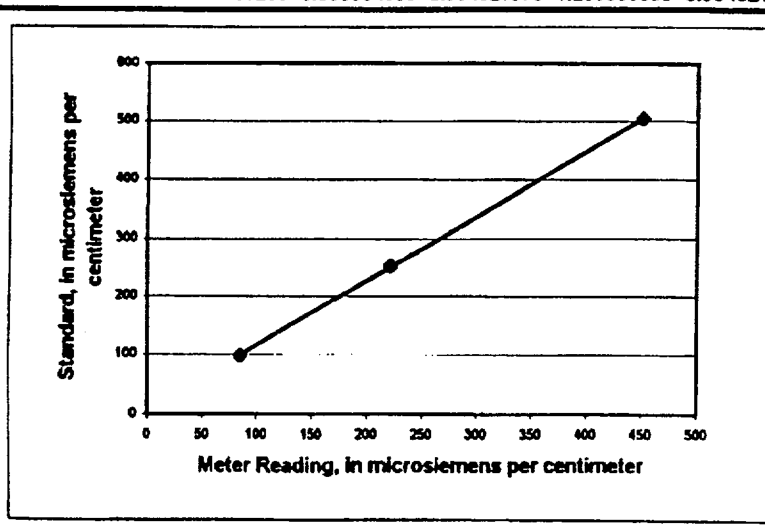
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999961807
R Square	0.999923615
Adjusted R S	0.99984723
Standard Erro	2.533333812
Observations	3

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	84012.24889	84012.24889	13090.5463	0.005564039
Residual	1	6.417780202	6.417780202		
Total	2	84018.66667			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5.118216526	2.847632995	1.797358204	0.323226035	-31.0642363	41.30066936	-31.0642363	41.30066936
X Variable 1	1.107853831	0.009682858	114.4139253	0.005564039	0.984821978	1.230885685	0.984821978	1.230885685



Determination by : C Savard

Date : 1/30/98

pH and Alkalinity Tritration

Site Name :	USW WT-24	pH :	8.61	CO3 endpoint (ml) :	0.25
Site ID :	365301116271301			CO3 (mg/L) =	6.15
SMF :				CO3 (meq/L) =	0.20
Date :	12/10/97	Sample volume (ml) :	40		
Time :	1526	Titrant normality :	0.01639	HCO3 endpoint (ml) :	5.35
Collected by :	C. Savard			HCO3 (mg/L) =	121.26
		Meter No. :	233263	HCO3 (meq/L) =	1.99

Time	Sample	Lot No.	Meter Reading
1818	7.0	965991-24	Adjust calibration knob to 7.0
1821	4.0	964407-24	Adjust slope knob to 4.0
1825	10.0	964975-24	10.02
1829	WT-24	-	8.61
1831	WT-24	-	8.60
1840	WT-24	-	8.61
	Titration		
1926	7.0	965991-24	6.98
1929	4.0	964407-24	3.88
1932	10.0	964975-24	10.11

Vol of titrant (ml)	pH	Change in vol.	Change in pH	pH change/ vol change
0.00	8.61			
0.05	8.52	0.05	0.09	1.800
0.10	8.42	0.05	0.10	2.000
0.15	8.29	0.05	0.13	2.600
0.20	8.17	0.05	0.12	2.400
0.25	8.02	0.05	0.15	3.000
0.30	7.89	0.05	0.13	2.600
0.40	7.73	0.10	0.16	1.600
0.50	7.59	0.10	0.14	1.400
0.70	7.39	0.20	0.20	1.000
0.90	7.23	0.20	0.16	0.800
1.10	7.12	0.20	0.11	0.550
1.30	7.00	0.20	0.12	0.600
1.60	6.83	0.30	0.17	0.567
1.90	6.73	0.30	0.10	0.333
2.20	6.61	0.30	0.12	0.400
2.60	6.48	0.40	0.13	0.325
3.00	6.35	0.40	0.13	0.325
3.40	6.20	0.40	0.15	0.375
3.80	6.05	0.40	0.15	0.375
4.20	5.87	0.40	0.18	0.450
4.50	5.72	0.30	0.15	0.500
4.80	5.50	0.30	0.22	0.733
4.90	5.40	0.10	0.10	1.000
4.95	5.35	0.05	0.05	1.000
5.00	5.30	0.05	0.05	1.000
5.05	5.20	0.05	0.10	2.000
5.10	5.15	0.05	0.05	1.000
5.15	5.06	0.05	0.09	1.800
5.20	4.94	0.05	0.12	2.400
5.25	4.80	0.05	0.14	2.800
5.30	4.66	0.05	0.14	2.800
5.35	4.51	0.05	0.15	3.000
5.40	4.36	0.05	0.15	3.000
5.45	4.24	0.05	0.12	2.400
5.50	4.13	0.05	0.11	2.200
5.55	4.05	0.05	0.08	1.600
5.60	3.96	0.05	0.09	1.800

Conductivity Worksheet

Site Name : USW WT-24
Site ID : 365301116271301
Date : 12/10/97
Time : 1440
Collected by : C. Savard

Meter : VWR A22066

Time	Name	Lot#	Meter
1440	Plug	--	1000
1443	101	97314	89
1445	250	97304	230
1447	495	97317	454
1500	WT-24	--	252 *
1502	WT-24	--	252 *
1503	WT-24	--	252 *

* Readings used for average

Average conductivity reading : 252

Corrected conductivity : 276

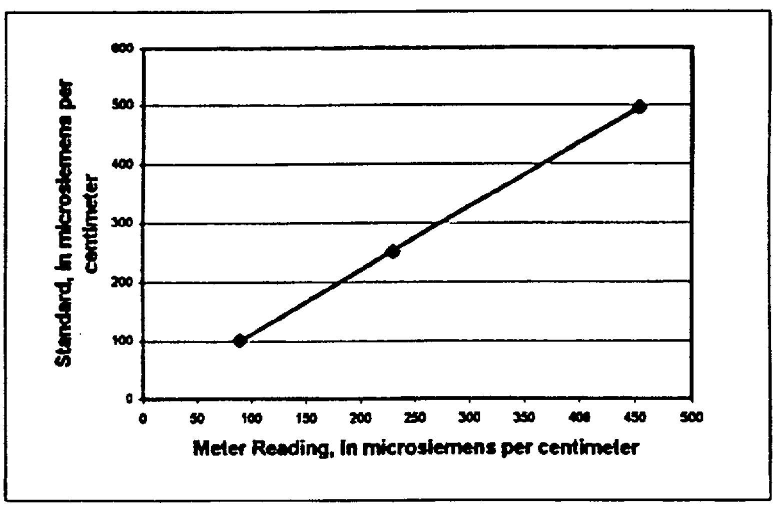
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999957534
R Square	0.999915071
Adjusted R S	0.999830142
Standard Erro	2.592776303
Observations	3

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	79147.27751	79147.27751	11773.508	0.005866984
Residual	1	6.722488956	6.722488956		
Total	2	79154			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.524242186	2.971118503	1.18616682	0.445918016	-34.2272361	41.27572044	-34.2272361	41.27572044
X Variable 1	1.080759733	0.009960387	108.5057971	0.005866984	0.954201558	1.207317907	0.954201558	1.207317907

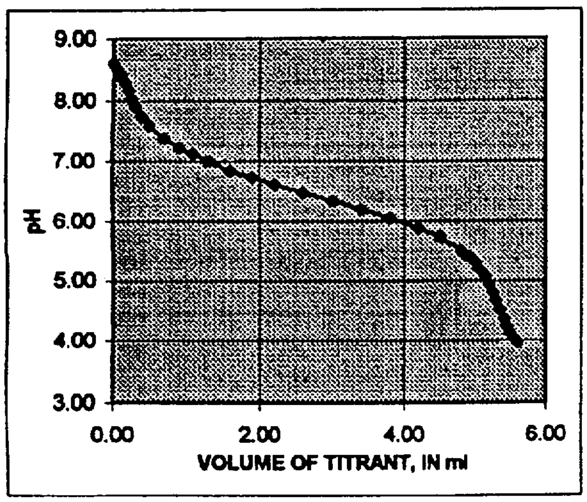


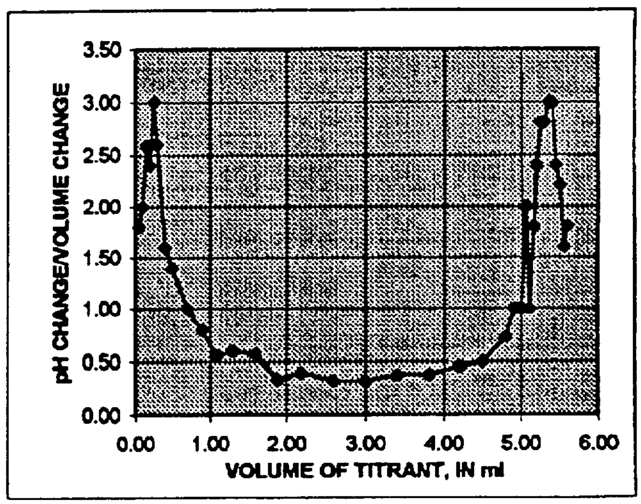
Determination by : C Savard

Date : 1/30/98

pH and Alkalinity Tritration

Site Name :	USW WT-24	pH :	8.61	CO3 endpoint (ml) :	0.25
Site ID :	365301116271301			CO3 (mg/L) =	6.15
SMF :				CO3 (meq/L) =	0.20
Date :	12/10/97	Sample volume (ml) :	40		
Time :	1526	Titrant normality :	0.01639	HCO3 endpoint (ml) :	5.35
Collected by :	C. Savard			HCO3 (mg/L) =	121.26
		Meter No. :	233263	HCO3 (meq/L) =	1.99





Determination by : C Savard

Date : 1/30/98

DTN:GS980108312322.005
TDIF:306605
File Name:wt-24.txt (annotations not on electronics)

Table Descriptions:
"parameter" data from samples collected at borehole USW WT-24, between 10-6-97 and 12-10-97

—; No Data Available
N/A ; No Analysis

Alkalinity (field)	mg/L as HC03	<— P 1592 Alkalinity		
WT-24	10/22/97	900	SPC00009539	135
WT-24	10/22/97	915	SPC00009551	135
WT-24	12/10/97	1445	SPC00526813	121
WT-24	12/10/97	1446	SPC00526814	121
WT-24	10/6/97	1400	SPC00009574	174*

* = laboratory analysis
Please make sure that "lab" and "field" are footnoted or stacked in the SEP table.

L168 - Borehole	C268 - Date	C87 - Time	L201 - SPC Number	Value for Parameter Listed

Barium	ug/L as Ba	<— P 1610 Barium		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	20
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	3
WT-24	12/10/97	1446	SPC00526816	—

Beryllium	ug/L as Be	<— P 1612 Beryllium		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<0.5
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<1.0
WT-24	12/10/97	1446	SPC00526816	—

Chloride	mg/L as Cl	<— P 5492 Chloride		
WT-24	10/6/97	1400	SPC00009578	11.1
WT-24	10/22/97	900	SPC00009542	9.1
WT-24	10/22/97	915	SPC00009552	8.8
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	8.9
Chromium	ug/L as Cr	<— P 1623 Chromium		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<5.0
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<14
WT-24	12/10/97	1446	SPC00526816	—
Cobalt	ug/L as Co	<— P 1624 Cobalt		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	6.2
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<12
WT-24	12/10/97	1446	SPC00526816	—
Copper	ug/L as Cu	<— P 1625 Copper		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<10
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<10
WT-24	12/10/97	1446	SPC00526816	—
Fluoride	mg/L as F	<— P 1782 Fluoride		
WT-24	10/6/97	1400	SPC00009578	1.3
WT-24	10/22/97	900	SPC00009542	0.8
WT-24	10/22/97	915	SPC00009552	0.7
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	0.8
Hydrogen 2 / 1 Ratio	Ratio Per Mil	<— P 2614 Delta Deuterium		
WT-24	10/6/97	1400	SPC00009580	-100.0
WT-24	10/6/97	1400	SPC00009580	-99.3
WT-24	10/22/97	900	SPC00009545	-99.5
WT-24	10/22/97	900	SPC00009545	-99.2
WT-24	10/22/97	900	SPC00009546	—
WT-24	10/22/97	900	SPC00009546	—
WT-24	12/10/97	1445	SPC00526819	-102.2
WT-24	12/10/97	1446	SPC00526820	-99

Iron	ug/L as Fe	<--- P 1645 Iron		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	282
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	11
WT-24	12/10/97	1446	SPC00526816	—
Lead	ug/L as Pb	<--- P 1649 Lead		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<10
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<100
WT-24	12/10/97	1446	SPC00526816	—
Lithium	ug/L as Li	<--- P 1650 Lithium		
WT-24	10/6/97	1400	SPC00009576	68.0
WT-24	10/22/97	900	SPC00009541	27.1
WT-24	10/22/97	915	SPC00009553	25.2
WT-24	12/10/97	1445	SPC00526815	46.6
WT-24	12/10/97	1446	SPC00526816	45.3
Magnesium	mg/L as Mg	<--- P 1652 Magnesium		
WT-24	10/6/97	1400	SPC00009576	1.2
WT-24	10/22/97	900	SPC00009541	1.5
WT-24	10/22/97	915	SPC00009553	1.4
WT-24	12/10/97	1445	SPC00526815	1.3
WT-24	12/10/97	1446	SPC00526816	1.2
Manganese	ug/L as Mn	<--- P 1653 Manganese		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	128
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	67.2
WT-24	12/10/97	1446	SPC00526816	—
Molybdenum	ug/L as Mo	<--- P 1656 Molybdenum		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	17
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<60
WT-24	12/10/97	1446	SPC00526816	—
Nickel	ug/L as Ni	<--- P 1660 Nickel		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<10
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<40
WT-24	12/10/97	1446	SPC00526816	—

Nitrogen 14 / 15 Ratio	Ratio Per Mil	<— P 6451 Delta Nitrogen 15		
WT-24	10/6/97	1400		N/A
WT-24	10/22/97	900	SPC00009538	5.6
WT-24	10/22/97	900	SPC00009538	—
WT-24	10/22/97	900	SPC00009554	—
WT-24	10/22/97	900	SPC00009554	—
WT-24	12/10/97	1445	SPC00526808	—
WT-24	12/10/97	1446	SPC00526809	—
Nitrate	mg/L as N	<— P 1809 Nitrate		
WT-24	10/6/97	1400	SPC00009578	—
WT-24	10/22/97	900	SPC00009542	0.37
WT-24	10/22/97	915	SPC00009552	—
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	—
Nitrite	mg/L as N	<— P 1664 Nitrogen, nitrite		
WT-24	10/6/97	1400	SPC00009578	—
WT-24	10/22/97	900	SPC00009542	0.012
WT-24	10/22/97	915	SPC00009552	—
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	—
Oxygen 18 / 16 Ratio	Ratio Per Mil	<— P 3112 Delta Oxygen 18		
WT-24	10/6/97	1400	SPC00009581	-13.5
WT-24	10/6/97	1400	SPC00009581	-13.2
WT-24	10/22/97	900	SPC00009545	-13.5
WT-24	10/22/97	900	SPC00009545	—
WT-24	10/22/97	900	SPC00009546	—
WT-24	10/22/97	900	SPC00009546	—
WT-24	12/10/97	1445	SPC00526819	-13.5
WT-24	12/10/97	1446	SPC00526820	-13.4
pH (Field)	Standard units	<— P 429 pH		
WT-24	10/6/97	1400	SPC00009574	8.3
WT-24	10/22/97	900	SPC00009539	8.1
WT-24	10/22/97	915	SPC00009551	8.1
WT-24	12/10/97	1445	SPC00526813	8.6
WT-24	12/10/97	1446	SPC00526814	8.6
Phosphate	mg/L as PO4	<— P 6302 Phosphate		
WT-24	10/6/97	1400	SPC00009578	—
WT-24	10/22/97	900	SPC00009542	0.13
WT-24	10/22/97	915	SPC00009552	—
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	—

Potassium	mg/L as K	<— P 1677 Potassium		
WT-24	10/6/97	1400	SPC00009576	3.5
WT-24	10/22/97	900	SPC00009541	2.5
WT-24	10/22/97	915	SPC00009553	2.4
WT-24	12/10/97	1445	SPC00526815	2.9
WT-24	12/10/97	1446	SPC00526816	2.9
Radon 222	pci/L	<— P 3370 Radon 222 Isotope		
WT-24	10/6/97	1400		N/A
WT-24	10/22/97	900	SPC00009556	760
WT-24	10/22/97	900	SPC00009556	—
WT-24	10/22/97	900	SPC00009557	—
WT-24	10/22/97	900	SPC00009557	—
WT-24	12/10/97	1445	SPC00526828	601
WT-24	12/10/97	1446	SPC00526829	—
Silica	mg/L as SiO2	<— P 5231 Silica		
WT-24	10/6/97	1400	SPC00009578	43
WT-24	10/22/97	900	SPC00009542	46
WT-24	10/22/97	915	SPC00009552	47
WT-24	12/10/97	1445	SPC00526817	35
WT-24	12/10/97	1446	SPC00526818	38
Silver	ug/L as Ag	<— P 1692 Silver		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<10
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<4.0
WT-24	12/10/97	1446	SPC00526816	—
Sodium	mg/L as Na	<— P 1693 Sodium		
WT-24	10/6/97	1400	SPC00009576	48
WT-24	10/22/97	900	SPC00009541	39
WT-24	10/22/97	915	SPC00009553	35
WT-24	12/10/97	1445	SPC00526815	39
WT-24	12/10/97	1446	SPC00526816	36
Specific Conductance (field)	microsiemens/cm	<— P 56 Specific Conductance		
WT-24	10/6/97	1400	SPC00009574	331
WT-24	10/22/97	900	SPC00009539	296
WT-24	10/22/97	915	SPC00009551	296
WT-24	12/10/97	1445	SPC00526813	276
WT-24	12/10/97	1446	SPC00526814	276

Strontium	ug/L as Sr	<— P 1694 Strontium		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	169
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	128
WT-24	12/10/97	1446	SPC00526816	—
Sulfate	mg/L as SO4	<— P 1836 Sulfate		
WT-24	10/6/97	1400	SPC00009578	18
WT-24	10/22/97	900	SPC00009542	15
WT-24	10/22/97	915	SPC00009552	16
WT-24	12/10/97	1445	SPC00526817	—
WT-24	12/10/97	1446	SPC00526818	16
Temperature (Field)	Degrees Celcius	<— P 595 Temperature		
WT-24	10/6/97	1400	SPC00009574	25.2
WT-24	10/22/97	900	SPC00009539	22.9
WT-24	10/22/97	915	SPC00009551	22.9
WT-24	12/10/97	1445	SPC00526813	—
WT-24	12/10/97	1446	SPC00526814	—
Tritium	Tritium Units (TU)	<— P 5717 Tritium		
WT-24	10/6/97	1400		N/A
WT-24	10/6/97	1400		N/A
WT-24	10/22/97	900	SPC00009537	<0.3
WT-24	10/22/97	900	SPC00009537	—
WT-24	10/22/97	900	SPC00009555	—
WT-24	10/22/97	900	SPC00009555	—
WT-24	12/10/97	1445	SPC00526802	—
WT-24	12/10/97	1446	SPC00526803	—
Vanadium	ug/L as V	<— P 1707 Vanadium		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<6.0
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<10
WT-24	12/10/97	1446	SPC00526816	—
Zinc	ug/L as Zn	<— P 1711 Zinc		
WT-24	10/6/97	1400	SPC00009576	—
WT-24	10/22/97	900	SPC00009541	<3.0
WT-24	10/22/97	915	SPC00009553	—
WT-24	12/10/97	1445	SPC00526815	<20
WT-24	12/10/97	1446	SPC00526816	—

Please note that the following SPC samples had no data avaliable but are listed on the TDIF:

SPC00526827 SPC00009577
SPC00009575 SPC00009579

DISTRICT CODE 08

UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY
365301116271301 - WT-24

PROCESS DATE 1-22-98

WATER-QUALITY DATA

DATE	TIME	AGENCY ANA- LYZING SAMPLE (CODE NUMBER) (00028)	PH WATER WHOLE LAB (STAND- ARD UNITS) (00403)	NITRO- GEN, NITRITE DIS- SOLVED (MG/L AS N) (00613)	NITRO- GEN, NO2+NO3 DIS- SOLVED (MG/L AS N) (00631)	PHOS- PHORUS ORTHO, DIS- SOLVED (MG/L AS P) (00671)	CARBON, ORGANIC TOTAL (MG/L AS C) (00680)	CALCIUM DIS- SOLVED (MG/L AS CA) (00915)	MAGNE- SIUM, DIS- SOLVED (MG/L AS MG) (00925)	SODIUM, DIS- SOLVED (MG/L AS NA) (00930)
OCT 1997										
06...	1400	80020.	7.9050	--	--	--	--	20.305	1.2010	47.667
22...	0900	80020.	7.9610	0.01200	0.36800	0.12500	0.50000	23.957	1.4830	38.732
22...	0915	80020.	7.9830	--	--	--	--	22.465	1.3850	35.208
DEC										
10...	1445	80020.	8.3490	--	--	--	0.40000	18.389	1.3040	39.015
10...	1446	80020.	8.2690	--	--	--	--	17.722	1.2270	36.154

WATER-QUALITY DATA

DATE	COPPER, DIS-SOLVED (UG/L AS CU) (01040)	IRON, DIS-SOLVED (UG/L AS FE) (01046)	LEAD, DIS-SOLVED (UG/L AS PB) (01049)	MANGA-NESE, DIS-SOLVED (UG/L AS MN) (01056)	MOLYB-DENUM, DIS-SOLVED (UG/L AS MO) (01060)	NICKEL, DIS-SOLVED (UG/L AS NI) (01065)	SILVER, DIS-SOLVED (UG/L AS AG) (01075)	STRON-TIUM, DIS-SOLVED (UG/L AS SR) (01080)	VANA-DIUM, DIS-SOLVED (UG/L AS V) (01085)	ZINC, DIS-SOLVED (UG/L AS ZN) (01090)
OCT 1997										
06...	--	--	--	--	--	--	--	--	--	--
22...	<10.000	282.27	<10.000	127.97	17.464	<10.000	<1.0000	168.87	<6.0000	<3.0000
22...	--	--	--	--	--	--	--	--	--	--
DEC										
10...	<10.000	11.459	<100.00	67.195	<60.000	<40.000	<4.0000	128.36	<10.000	<20.000
10...	--	--	--	--	--	--	--	--	--	--

365301116271301 - WT-24

WATER-QUALITY DATA

DATE	LITHIUM DIS-SOLVED (UG/L AS LI) (01130)	TRITIUM TOTAL (PCI/L) (07000)	BROMIDE DIS-SOLVED (MG/L AS BR) (71870)	TRITIUM 2 SIGMA WATER, WHOLE, TOTAL (PCI/L) (75985)	RN-222 2 SIGMA WATER, WHOLE, TOTAL, (PCI/L) (76002)	RADON 222 TOTAL (PCI/L) (82303)	N15/N14 NO3 FRAC WATER FLTRD 0.45 U PER MIL (82690)	SPE-CIFIC CON-DUCT-ANCE LAB (US/CM) (90095)	ALKA-LINITY LAB (MG/L AS CACO3) (90410)
OCT 1997									
06...	68.000	--	0.55500	--	--	--	--	335.00	142.70
22...	27.053	<1.0000	0.11200	1.0000	29.000	760.00	5.6000	293.00	--
22...	25.154	--	0.11400	--	--	--	--	300.00	109.30
DEC									
10...	46.580	--	--	--	41.000	601.00	--	272.00	--
10...	45.280	--	0.95600	--	--	--	--	268.00	108.57

Stable δD and $\delta^{18}O$ Values

Sample #	Extn Log #	$\delta^{18}O_{smow}$	δD_{smow}	LabCmnts
WT-24 10/6/97@1400	235-H-11		-100.0	YMP waters, 8/97
WT-24 10/6/97@1400	235-H-12		-99.3	YMP waters, 8/97
WT-24 10/6/97@1400	175-W-5	-13.5		YMP waters, 8/97
WT-24 10/6/97@1400	175-W-6	-13.2		YMP waters, 8/97
WT-24 971022	238-H-7		-99.5	
WT-24 971022	238-H-8		-99.2	
WT-24 971022	177-W-5	-13.5		
WT-24 971210	238-H-5		-102.2	
WT-24 971210	238-H-6		-99.0	
WT-24 971210	177-W-6	-13.5		
WT-24 971210	177-W-7	-13.4		

CALCITE/SILICA - CARBONATE STABLE ISOTOPES

Accept?	HD #	Locality	Sample #	Extn Log #	d13C pdb
☐ Yes		USW WT-24	WT-24 971022	20-DIC-1	-11.7
☐ Yes		USW WT-24	WT-24 971022	20-DIC-2	-12.1
☐ Yes		USW WT-24	WT-24 971022	22-DIC-1	-11.7
☐ Yes		USW WT-24	WT-24 971022	22-DIC-2	-11.8
☐ Yes		USW WT-24	WT-24 971210	25-DIC-1	-10.7
☐ Yes		USW WT-24	WT-24 971210	25-DIC-2	-10.8

6/9/98

DRAFT DISCLAIMER

This contractor document was prepared for the U.S. Department of Energy (DOE), but has not undergone programmatic, policy, or publication review, and is provided for information only. The document provides preliminary information that may change based on new information or analysis, and is not intended for publication or wide distribution; it is a lower level contractor document that may or may not directly contribute to a published DOE report. Although this document has undergone technical reviews at the contractor organization, it has not undergone a DOE policy review. Therefore, the views and opinions of authors expressed do not necessarily state or reflect those of the DOE. However, in the interest of the rapid transfer of information, we are providing this document for your information.

PROPOSAL

Geodetic Monitoring of the Yucca Mountain Region using Continuous Global Positioning System Measurements

to

Department of Energy
Yucca Mountain Project

from

Nevada Bureau of Mines and Geology
University of Nevada, Reno
Mail Stop 178
Reno, NV 89557-0088

Jonathan G. Price
Director/State Geologist
telephone: 702-784-6691 extension 126
fax: 702-784-1709
e-mail: jprice@nbmg.unr.edu

STATEMENT OF WORK

The specific tasks for this funding are:

(1) to subcontract with California Institute of Technology (Cal Tech), under the supervision of Professor Brian Wernicke, for geodetic monitoring of the Yucca Mountain region; a copy of the Cal Tech proposal is attached to this proposal (the task description for the subcontract to Cal Tech is given below);

(2) to develop a quality assurance plan for geodetic monitoring using continuous GPS measurements, and

(3) to double-check the assumptions and processing done under the Cal Tech subcontract.

We plan to accomplish this by hiring a Ph.D.-level geodesist for a four-year period and a slightly more than half-time technician. In addition, we have added the expenses of two graduate students for two years each, to pursue aspects of the neotectonics directly related to the geodetic data collected near Yucca Mountain. Apart from the funds for the geodesist, no faculty salaries are requested.

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California 91125

Office of Sponsored Research
(626) 395-6357

Mail Stop 213-6
Fax: (626)795-4571
E-mail: Office@sponsres.caltech.edu

June 9, 1998

Ms. Terri Garside
University of Nevada, Reno
Nevada Bureau of Mines and Geology
1664 N. Virginia Street
Reno, Nevada 89503

SUBJECT: Proposal to the Department of Energy

Dear Ms. Garside:

On behalf of the California Institute of Technology and Professor Brian P. Wernicke, I am pleased to submit the enclosed proposal for a project entitled, "Geodetic Monitoring of the Yucca Mountain Region with Continuous GPS." I understand that the work of Dr. Wernicke will be incorporated into a proposal to be submitted to the Department of Energy by the University of Nevada, Reno (UNR) on behalf of Dr. Jonathan G. Price.

The Caltech proposal contemplates a four-year project beginning June 15, 1998, at an estimated cost of $2,766,824. In the event that an award is made to UNR, Caltech anticipates participating in the project under a subcontract that is subject to mutually agreeable terms and conditions.

Please contact me at (626) 395-6073 if you have any questions about the budget or other administrative matters pertaining to this proposal.

Sincerely yours,

Richard Seligman

Richard P. Seligman
Director, Sponsored Research

RPS:lm

cc: Dr. Brian P. Wernicke
Dr. Edward Stolper

PROPOSAL

Title:

Geodetic monitoring of the Yucca Mountain region with continuous GPS

Principal Investigator:

Brian P. Wernicke
California Institute of Technology

Co-Principal Investigators

James L. Davis
Richard A. Bennett
Harvard-Smithsonian Center for Astrophysics

Performance Period:

15 June 1998 to 31 May 2002

First-Year Budget:

$724,761

Total Budget, Years 1-4:

$2,766,824

PROJECT DESCRIPTION

Need for Assistance

Previous geodetic monitoring of the Yucca Mountain region indicates that extensional tectonic or volcanic strain is accumulating there at a rate of about 50 nanostrains per year (nstr/yr), approximately 10 to 100 times estimates of strain accumulation based on geologic studies of young faults and volcanoes across the area (Wernicke et al., 1998). The discrepancy is most readily accounted for by the hypothesis that the Yucca Mountain region is experiencing a transient interval of anomalously rapid extension, atypical of averages taken over a million-year time scale. If this is correct, then previous hazards assessments by the Department of Energy for the proposed high-level nuclear waste repository, including the frequency and degree of seismic shaking, deformation of the repository itself, and the probability of volcanic disruption, may be seriously underestimated, because these assessments are based on averaging over geologic time and do not account for the possibility that the next 10,000 years may see 10-100 times more tectonic or volcanic activity than the geologic average.

The apparent motions observed between 1991 and 1997 are based on campaign-mode GPS surveys of five sites deployed across Yucca Mountain with a total aperture of 33 km. The small number of sites in the network and the fact that we collected only one day of GPS data each year limit the usefulness of the results beyond showing that there are measurable rates across the area in the mm/yr range. Issues involved in interpreting the data, including the possibility that they are spatially and temporally related to afterslip or viscous relaxation of the deep crust following the 1992 Little Skull Mountain earthquake, are not resolvable with the current data set, and are unlikely to be resolvable by 2002 with any continued campaign-mode surveys.

Methods

The technology now exists to resolve intersite velocities at the level of a fraction of a millimeter per year within just a few years of monitoring, using continuous-mode recording of GPS data from networks of deep-anchored bedrock monuments. With a dense network of such monuments deployed around Yucca Mountain, and a sparse network deployed over a broader region, we could achieve the same rate accuracy in 2-3 years as we did for the 6 years of campaign-mode operation, or perhaps better. With the improved spatial resolution accorded by a dense network, we would be able to (1) evaluate the accuracy of the campaign-based rates; (2) determine if the rates are slowing with time following the earthquake; (3) determine if the deformation is spatially related to the earthquake or perhaps other faults in the region, or is related to an unknown source such as a magma chamber; and (4) determine whether rates across the proposed repository site are anomalously high relative to surrounding areas.

In 1996 and 1997, our research team built the first remote continuous-mode GPS network using deep-anchored bedrock monuments. The 18-site network spans the northern Great Basin region, and has site characteristics and climate similar to the Yucca Mountain area, including low levels of atmospheric moisture, dry, relatively unfractured bedrock, and good satellite visibility (Bennett et al., 1998). Daily horizontal intersite positions are repeatable to within 2-3 mm, the lowest yet achieved for any GPS network. After just one year of monitoring, we have determined a coherent velocity field for the northern Great Basin with rate uncertainties at the millimeter level or lower (Bennett et al., 1998). Based on these results, we project that the standard deviation in intersite velocities will be in the 0.2 mm/yr range or less by 2002.

Given our success with the northern Great Basin continuous network, we believe a similar network established around Yucca Mountain will conclusively resolve the issue of whether strain accumulation is rapid and anomalously high relative to surrounding areas, or whether transient motions related to the 1992 earthquake or some other error source is responsible for the 1991-1997 results.

Proposed Research

We propose to establish a 30-site network of deep-anchored bedrock geodetic monuments, including 15 more-or-less co-located with the DOE/USGS Yucca Mountain Project network, an additional 5 sites in the immediate vicinity of Yucca Mountain, and 10 sites deployed east and west of Yucca Mountain at larger aperture to establish regional context of the strain.

The local network's 50-km aperture is broad enough that discrimination of velocities spatially near the epicenter of the 1992 earthquake and those far from it will be possible. In addition, the local network will discriminate whether strain accumulation is spatially biased toward the Rock Valley fault, Bare Mountain fault, or numerous active faults within Yucca Mountain itself.

The regional network will be deployed at larger aperture (ca. 100-200 km) on either side of the Yucca Mountain, and will be designed to establish how localized shear deformation in the southern Basin and Range region spreads eastward into the northern Great Basin. The large aperture network will include 3-4 far-field sites to establish a geodetic reference frame of the site motions relative to the Colorado Plateau and the Sierra Nevada. It has long been suspected that some fraction of the 8-10 mm/yr of right-shear along the eastern California shear zone is shunted eastward and expressed as extensional deformation in the northern Basin and Range. Shear deformation measured along an array just south of Yucca Mountain will be compared with that from an array to the north of it, and overall extensional strain of the volcanic zone will also be measured. The regional network will therefore serve to determine the overall framework of strain accumulation near Yucca Mountain, for which no data are currently available.

Work Plan

We propose to begin site selection, permitting and installation of the network on June 1 1998. Site selection and applications for permits will be accomplished in June, 1998. We are currently the most experienced research group in the world in the permitting and construction of telemetered, remote continuous GPS sites with deep-anchored bedrock monumentation. All sites are expected to be on federal land. Rights-of-Way for identical sites have already been granted througout Nevada, California and Utah, and we will coordinate these precedents and procedures between agencies (BLM, DOE, USFS, and USAF) so that there is no duplication of effort. Processing of applications for Rights-of-Way Grants for the northern Nevada sites averaged about 8-9 weeks. We will use the support of the Nevada congressional delegation to communicate the high priority of the project to the Nation. We expect processing of applications filed by late June to be complete by early August. Because contracting expertise for the 18 Great Basin sites is already in-place, we anticipate construction and site installation by Earthsafe and UNAVCO will take approximately two months. Daily downloading of continuous GPS data from the network via dialup telemetry links would begin no later than November 1, 1998. B. Wernicke will be in charge of all aspects of permitting, network construction and maintenance.

Processing of GPS data will be done on a daily basis at the Harvard-Smithsonian Astrophysical Observatory, using techniques described in Wernicke et al. (1998) and Bennett et al. (1998). Because we have already established a processing center, there would be no delay in initiating data processing once the network is built, and significant motions will probably be detectable by 2000. J. Davis and R. Bennett will be responsible for data processing, producing a geodetic solution, and time-series analysis of the solution. Wernicke, Bennett and Davis will jointly interpret the geological significance of the results.

UNR will have full access to all planning activities, construction and installation activities, raw GPS data, and network solutions

Budget

Based on our previous experience with the 18 sites in the northern Great Basin, we have constructed a four-year budget over five fiscal years. Principal budget components include partial salary support for Wernicke, an administrator and a technician; travel expenses for Wernicke and the technician to install and maintain the sites; equipment required to build the sites, including GPS equipment, telemetry equipment, and other equiment to be installed directly on-site; materials and supplies to maintain the network; and three subcontracts. The first subcontract (Earthsafe), entirely in Years 1 and 2, is for construction, for which a detailed cost breakdown is attached. The second (Harvard-Smithsonian) is for processing and generating a geodetic solution, with estimated costs and work plan attached. The third (UNAVCO) is for installation of telemetry components and technical expertise in GPS equipment maintenance and repair of telemetry components. The subcontracting arrangements duplicate those already in-place at Caltech for the northern Great Basin network, providing significant economies of scale, including avoiding the high cost of assembling and training a new team, and most importantly minimizing the time required to begin network operations.

We note that the overall cost for permitting, construction and four years of monitoring is comparable to existing networks, including the NSF-funded northern Great Basin network, which has a total budget of $2.1 M for construction and 4-5 years of monitoring of 18 sites; and the southern California network, for which some $15 M has been allocated for the construction and monitoring of about 200 sites.

Terms and Conditions of Subcontract

The California Institute of Technology (Caltech) has recent proven expertise in remote, continuous network geodesy using braced, deep-anchored monumentation, and that in the interest of expediting the project at the minimum cost, the Yucca Mountain network will to the maximum extent possible be built and monitored under same terms and conditions as the previous efforts by Caltech in the northern Great Basin. In order to minimize delay, in particular delay caused by requirements to significantly alter Caltech's scientific and administrative practices in establishing the northern Great Basin network, the University of Nevada, Reno (UNR) will grant Caltech the authority to directly manage all aspects of site selection, permitting, network installation, maintenance, and data processing. Specifically:

(1) Site selection. Caltech will make every reasonable effort to accommodate suggestions regarding site locations from UNR scientists and other interested parties, but retains the authority to make the final decision on network geometry.

(2) Permitting. Caltech personnel will communicate directly, and negotiate all terms, with the appropriate private, state of federal officers responsible for issuing Right-of-Way Grants to access, construct and maintain the sites. It is understood that no approvals will be required from the Department of Energy (DOE), UNR or other parties not directly charged with granting the permit, i.e. Caltech would act as any member of the general public applying for such a permit. It is understood that in order for the project to move forward in a timely way, the DOE and UNR will recognize procedures and precedents for identical federal permits issued throughout the State of Nevada to the maximum extent possible.

(3) Installation. Caltech will manage all aspects of installation. DOE and UNR will recognize Caltech procurement and purchasing procedures as sufficient for the administration of the project, including Caltech practices for selection of vendors and subcontractors for site materials and construction. Where necessary, Caltech will be responsible for administering the project in accordance with federal contracting policies as required by federal law, for example following prevailing wage practices for construction employees, etc. It is understood that all equipment related to the Caltech subcontract will be owned by Caltech until the termination of

the project. At that time, Caltech retains the right to own the equipment if it retains responsibility for the network through a new contract for maintenance and data processing, with DOE or another agency. If Caltech does not retain such responsibility, it is understood that ownership of the equipment will revert to the Prime Contractor.

(4) Maintenance. Caltech personnel will be directly responsible for all maintenance of the sites, including a subcontract to University Navstar Consortium (UNAVCO) for technical expertise in both installation and site maintenance.

(5) GPS data processing will be performed under subcontract by the Harvard-Smithsonian Astrophysical Observatory. All GPS data will be made available as soon as feasible to UNR scientists, who are free to conduct their own solutions and analyses of the data. In any event, raw data files in RINEX format will be made generally available to the public within 6 months of collection through the UNAVCO archive or other appropriate vehicle. Caltech will retain copyright of all raw data generated during the project. It is understood that in addition to any analysis of raw GPS data that would be performed by UNR personnel, Caltech will provide UNR and DOE with a full geodetic solution of the network approximately every three months beginning about one year after the start of the project, using GAMIT data reduction software and the GLOBK software to incorporate precise orbits and a global reference frame.

(6) Quality Assurance/Quality Control. The Prime Contractor will be responsible for meeting any reasonable Quality Assurance/Quality Control measures that may be required by the DOE. Caltech will cooperate by providing necessary documentation and full access to its activities related to the project. It is to be understood however that in no instance will UNR or DOE issue a Stop Work Order or otherwise withhold funds on the basis of perceived inadequacy of Quality Assurance or Quality Control measures.

References

Bennett, R. A., Wernicke, B., and Davis, J. L., 1998, Continuous GPS measurements of contemporary deformation across the northern Basin and Range province: *Geophysical Research Letters*, v. **25**, p. 563-566.

Wernicke, B., Davis, J. L., Bennett, R. A., Elosegui, P., Abolins, M. J., Brady, R. J., House, M. A., Niemi, N. A., and Snow, J. K., Anomalous strain accumulation in the Yucca Mountain area, Nevada: *Science*, v. **279**, p. 2096-2100.

EARTHSAFE

Geological and Environmental Consulting

15027 Lashburn Street, Whittier, CA 90604
Phone/FAX (562) 903-9123 CSL # 734057 A-HAZ

Dr. Brian P. Wernicke
Department of Earth Science
California Institute of Technology
Pasadena, CA

May 14, 1998

Subject: Deeply anchored GPS monument construction in vicinity of Yucca Mountain, Nevada, including Eastern California, Northwestern Arizona.

Dr. Wernicke,

We appreciate this opportunity to submit a proposal for the construction of ultra stable GPS antenna mounts for the Yucca Mountain project. We will provide the equipment, material and labor necessary to construct each monument in conformance with the specifications outlined in the statement of work, subsequent modifications and to the satisfaction of an inspection team. See the attached spreadsheets for a breakdown of the estimated cost for each monument based upon time records for similar work in California, Nevada, Oregon, Utah and Washington.

EARTHSAFE is a geological consulting and construction firm experienced in the installation of Wyatt design deeply-anchored GPS monuments. We use a can-do spirit, and will finish the project regardless of any obstacles encountered during construction (poor soil conditions, difficult site locations, etc.). Of the 23 monuments we have constructed across the Western United States, all are transmitting data and have had no problems related to our work.

For this project, we will provide all materials listed on the attached spreadsheet. All other materials including the GPS antenna, the ray dome, the antenna cable, the GPS receiver, the solar power supply system, the phone modem and suitable enclosures for the electronic hardware and batteries will be provided by others.

We will drill the monument, install the various casings, grout the monument, weld the monument top, install posts for the GPS receiver and its hardware and a foundation for the battery box. We will secure the site with either a 30 by 30 foot chain link fence topped with barbed wire or a barbed wire fence on sturdy posts drilled and concreted into bed rock. When we are finished, the site will be ready for installation of the antenna and telemetry components.

Proposal

We plan travel segments of ten days, completing four monuments per trip, approximately eight trips. This schedule decreases use of overtime to a minimum and the number of large trucks impacting each site. The drill rig will remain in the field at the next site to be constructed.

We will provide a superintendent, a drill rig operator, a driller's assistant and three laborers.

At each monument site, the vertical and slant borings and fence holes will be drilled foremost. After insertion of the casings and there is no longer a need for the drill rig, we will load and send it to the next site to set up and prepare to drill. The remaining crew will form cement pad, grout, weld and install fence and monument hardware. The two crews will work consecutively to optimize use of labor.

General Assumptions

We have included the cost of the bagged grout mix in our proposal. We estimate 50 sacks per site, but have seen an individual site consume more than two-hundred bags to achieve the desired result. Additional bags of grout will be billed on a labor time and material cost basis.

We estimate a total of 800 miles round trip to complete four sites.

Labor for gathering materials and construction of the foam padded casings is included in the cost for each site.

Difficult drilling and construction conditions requiring additional hours will be billed at the rates for labor and per diem in accordance with the attached spreadsheet. Sites requiring additional materials such as casings or drilling fluids will be billed at the invoice cost plus G&A and profit. We charge a lump sum for our drilling equipment per site. No additional amounts will be charged for the drill rig, air compressor, company trucks and other company equipment for additional time due to construction delays.

If the need should arise for additional rental equipment, such as forklift, Bobcat, we will assess the needs at several sites so that rental equipment can be most efficiently used. We do not want to include these costs until the need is established. If needed, this equipment will be charged at the invoice rate plus G&A and profit.

If you have any questions concerning this proposal, please do not hesitate to contact our office at (562) 903-9123. Thank you.

Caltech Yucca Mountain Project
TASK; PROVIDE GPS SITE CONSTRUCTION
FURNISH LABOR, EQUIPMENT AND MATERIAL FOR SITE CONSTRUCTION.

CONTRACTOR: EARTHSAFE
LOCATIONS : Eastern California, Nevada and Arizona.

COST ELEMENTS BREAKDOWN

ITEM	COST ELEMENTS				REFERENCE SCHEDULE AND PAGE No.
1	DIRECT LABOR	RATES	HOURS	AMOUNT	CESD, PAGE 1
	LABORER(4 MAN)	$ 22.49	106	$ 2,383.90	
	OPERATOR (1 MAN)	$ 40.10	26	$ 1,042.47	
	SUPERINTENDENT (1 MAN)	$ 39.85	26	$ 1,036.04	
	TOTAL DIRECT LABOR			$ 4,462.40	
		RATES	BASE		
2	OVER TIME	$ 4,462.40	0.166666667	$ 743.73	
	TOTAL OVER TIME			$ 743.73	
	MATERIAL			$ 2,922.40	CESD, PAGE 2
	MATERIAL BURDEN	15	PERCENT	$ 438.36	
	TOTAL MATERIAL			$ 3,360.75	
3	OTHER DIRECT COSTS				
	Per Diem			$ 1,395.00	
	Mob-Demob			$ 600.00	CESD, PAGE 3
	EQUIPMENT			$ 3,823.00	CESD, PAGE 3
	SUBTOTAL COST			$ 14,384.89	
4	G&A	13.5	PERCENT	$ 1,941.96	
	SUBTOTAL COST			$ 16,326.85	
	Contractor Profit	7.95	PERCENT	$ 1,297.98	
	COST per Monument			$ 17,624.84	
	Cost of 30 Monuments			$ 528,745.06	

Caltech Yucca Mountain Project
TASK; PROVIDE GPS SITE CONSTRUCTION
FURNISH LABOR, EQUIPMENT AND MATERIAL FOR SITE CONSTRUCTION.

CONTRACTOR: EARTHSAFE

COST ELEMENTS SUPPORTING DATA (CESD)

ITEM	COST ELEMENT			
3A	**DIRECT LABOR**	RATES		
	LABORER			
	BASE PAY	$ 16.00		
	SUBTOTAL			$ 16.00
	PAYROLL TAX 13.85%	$ 2.22		
	WORKMANS COMP 13.71%	$ 2.19		
	GEN LABOR INS 13.00%	$ 2.08		
	SUBTOTAL			$ 6.49
	TOTAL			$ 22.49
	DRILL OPERATOR			
	BASE PAY	$ 30.00		
	SUBTOTAL			$ 30.00
	PAYROLL TAX 13.85%	$ 4.16		
	WORKMANS COMP 6.8%	$ 2.04		
	GEN LABOR INS 13.00%	$ 3.90		
	SUBTOTAL			$ 10.10
	TOTAL			$ 40.10
	SUPERINTENDANT			
	BASE PAY	$ 35.00		
	SUBTOTAL			$ 35.00
	PAYROLL TAX 13.85%	$ 4.85		
	WORKMANS COMP	$ -		
	GEN LABOR INS 13.00%			
	SUBTOTAL			$ 4.85
	TOTAL			$ 39.85

Caltech Yucca Mountain Project
TASK; PROVIDE GPS SITE CONSTRUCTION
FURNISH LABOR, EQUIPMENT AND MATERIAL FOR SITE CONSTRUCTION.

CONTRACTOR: EARTHSAFE

COST ELEMENTS SUPPORTING DATA (CESD)								**PAGE 2**
ITEM	COST ELEMENT							
3B	**DIRECT MATERIAL**	QTY	UNIT	UNIT PRICE		EXTENSION		
	2 1/2" PVC Pipe Sch 40	100	LF	$	0.96	$	96.00	
	1 1/4" Galv Pipe Sch 80 T&C	168	LF	$	2.36	$	396.48	
	3/4" X 2 5/8" Diam. Insul Foam	10	EA	$	14.26	$	142.60	
	Non Shrink Grout	50	SKS	$	11.96	$	598.00	
	Gussets	4	EA	$	3.95	$	15.80	
	Reinforcing steel, 1/2"	8	BAR	$	4.74	$	37.92	
	Duct/Strapping tape	10	EA	$	5.65	$	56.50	
	Misc. Supplies	1	EA	$	75.00	$	75.00	
	Fuel	160	GAL	$	1.49	$	238.40	
	Welding Rod	5	LBS	$	3.49	$	17.45	
	Hot Shot PVC Glue	0.5	QT	$	9.51	$	4.76	
	Spray Paint	2	EA	$	6.50	$	13.00	
	1" by 10 Foot Galvanized Pipe	1	EA	$	11.50	$	11.50	
	2.5" by 5 Foot Galvanized Pipe	1	EA	$	15.29	$	15.29	
	Grounding Rod	1	EA		$11.85		$11.85	
	10 GA THHN Wire	50	LF		$0.08		$4.00	
	Grounding Hardware	4	EA		$3.25		$13.00	
	Unistrut Mounts	2	EA		$11.80		$23.60	
	Concrete	20	EA		$3.40		$68.00	
	Concrete Form	1	SF		$10.25		$10.25	
	Fence- Barbed Wire w/Gate	120	LF		$5.40		$648.00	
	Antenna Adaptor Base	1	EA		$425.00		$425.00	
	TOTAL					$	2,922.40	

Caltech Yucca Mountain Project
TASK: PROVIDE GPS SITE CONSTRUCTION
FURNISH LABOR, EQUIPMENT AND MATERIAL FOR SITE CONSTRUCTION.

CONTRACTOR: EARTHSAFE

COST ELEMENTS SUPPORTING DATA (CESD)

ITEM	COST ELEMENT				
3 C	**OTHER DIRECT COSTS**	QTY	UNIT	UNIT PRICE	EXTENSION
1	PER DIEM	18	DAY	$ 77.50	$ 1,395.00
	MOB-DEMOB		LS		$ 600.00
2	EQUIPMENT				
	IR ECM 450-Y HYDRAULIC DRILL	3	DAY	$ 245.00	$ 735.00
	IR400 CFM 200 PSI AIR COMP	3	DAY	$ 225.00	$ 675.00
	DRILL ROD	3	DAY	$ 26.00	$ 78.00
	GROUT PLANT	3	DAY	$ 115.00	$ 345.00
	24' BOX TRUCK	3	DAY	$ 105.00	$ 315.00
	SERVICE TRUCK	6	DAY	$ 50.00	$ 300.00
	TRUCK/ 5 AXLE/TRAILER	3	DAY	$ 295.00	$ 885.00
	300 GAL WATER TANK W/ PUMP	3	DAY	$ 35.00	$ 105.00
	MISC. TOOLS	3	DAY	$ 15.00	$ 45.00
	ESTIMATED BIT WEAR	1	LS	$ 55.00	$ 55.00
	ARC WELDER	3	DAY	$ 50.00	$ 150.00
	CEMENT MIXER	3	Day	$ 45.00	$ 135.00
	TOTAL				$ 3,823.00

SMITHSONIAN ASTROPHYSICAL OBSERVATORY
60 Garden Street, Cambridge, MA 02138

(617) 495-7000

22 May 1998

Brian Wernicke
Division of Geological and Planetary Sciences
California Institute of Technology 170-25
1200 E. California Blvd.
Pasadena, California 91125

The Smithsonian Institution, pursuant to your request, is pleased to submit this letter Proposal P4395-5-98 for a four (4) year Cost Reimbursement (No Fee) Research and Development Contract with Nonprofit Organizations in the amount of $594,380 for Continuous GPS in the Region of Yucca Mt., Nevada that could commence on 1 June 1998 and continue through 31 May 2002.

The Statement of Work (SOW), Detailed Estimate of Cost and Budget Justification are attached.

The Smithsonian Institution, an independent trust establishment was created by an act of the Congress of 1846 to carry out the terms of the will of James Smithson of England, who had bequeathed his entire estate to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." After accepting the trust property for the United States, Congress vested responsibility for administering the trust in a Smithsonian Board of Regents.

The Smithsonian performs research, educational and other special projects supported by grants and contracts awarded under the cost principles of the Federal Acquisition Regulation, Subpart 31.7 Contracts with Nonprofit Organizations. It is audited by the Defense Contract Audit Agency, Landover, Maryland.

The Charter of the Smithsonian Institution carries a mandate for the "increase and diffusion of knowledge among men." Therefore, any grant or contract that may be awarded as a result of this proposal must be unclassified, in order not to abridge the Institution's right to publish, without restriction, findings that result from this research project.

Considering the nature of the proposed effort, it is requested that a Cost-Reimbursement (No Fee) Research and Development Contract with advance payment by electronic funds transfer be awarded to cover the proposed project in accordance with Subpart B Section .22(b) of OMB Circular No. A-110 dated November 19, 1993.

Pursuant to Subpart C, Section .33 and .34 of OMB Circular No. A-110 dated November 19, 1993, it is requested that title to all exempt property and equipment purchased or fabricated under the proposed contract be vested irrevocably in the Institution upon acquisition.

In accordance with an agreement between the Office of Naval Research and the Smithsonian, the Institution operates with predetermined fixed overhead rates with carry-forward provisions. For Fiscal Year 1996 and beyond, the Indirect Cost and Fringe Benefits Rates are developed in accordance with the Office of Management and Budget Circular (OMB) A-122: Cost Principles for nonprofit organizations and OMB Circular A-88. The following provisional rates, provided by ONR Rate Determination letter dated 26 September 1997, shall be used for forward pricing and billing purposes for Fiscal Year 1998. The Fringe Benefits Rate will be applied to the Total Direct Labor Costs. The Material Overhead Rate will be applied to the cost of materials, equipment and subcontracts. The Direct Operating Overhead Rate will be applied to the Direct Labor and Benefits costs. The G&A Rate will be applied to the base consisting of total costs except the costs associated with the materials, equipment and subcontracts.

The FY 1998 Provisional Rates are:

Material Overhead Rate	4.0%	(Cost of materials, equipment and subcontracts)
Leave Rate	15.5%	(Total Productive Labor Costs less paid leave and training (Productive Labor))
Fringe Benefits Rate	28.0%	(Total Direct Labor Costs)
Direct Operating Overhead Rate	23.3%	(Total Direct Labor and Fringe Benefits Costs)
General and Administrative Rate (G&A)	12.4%	(Base consists of Direct Operating Activities less Net Costs Associated with materials, subcontracts and equipment)
Central Engineering Overhead Rate	21.4%	(Central Engineering Direct Labor and Benefits Costs)

Rate verification can be made by contacting Ms. Deborah K. Rafi, ONR Contracting Officer for Indirect Cost Rates, Office of Naval Research, University Business Affairs Directorate, Indirect Cost Branch, Code 144, Room 129, Ballston Center Tower No. 3, 800 Quincy Street, Arlington, Virginia 22217-5661; telephone (703) 696-5641.

Engineering services are provided by the Central Engineering Department as a Cost Center. Charges by the department to research projects are inclusive of Direct Labor, Fringe Benefits, and Central Engineering Overhead.

CERTIFICATIONS

Pursuant to Executive Order 12549 and implementing rule (FAR 52.209-5), the Smithsonian Institution certifies that it presently is not debarred, suspended, proposed for debarment, declared ineligible or voluntarily excluded from covered transactions by any Federal department or agency.

> Pursuant to Section 1352, Title 31, United States Code (USC) and implementing rule (FAR 52.203-12), the Smithsonian Institution certifies that no Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress on his or her behalf in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment or modification of any Federal contract, grant, loan or cooperative agreement.

The program will be conducted by the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. The program will be performed under the direction of Dr. James L. Davis, as the Principal Investigator, within the Radio and Geoastronomy Division, with Dr. Philip C. Myers as the Associate Director of the Division.

Inquiries of a technical nature should be directed to Dr. James L. Davis, Mail Stop 42, Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, Massachusetts 02138, telephone (617) 496-7640. Inquiries and documents of a contractual nature should be directed to Dr. John G. Harris, Mail Stop 23, same address, telephone (617) 495-7446.

Sincerely yours,

Irwin Shapiro

Irwin I. Shapiro
Director

JGH/cm
Enclosures (2)

Statement of Work

Dr. James Davis will analyze the GPS time series, developing and applying statistical tests. The techniques to be developed will involve principal component analyses, maximum likelihood methods. and other methods and will be aimed at identifying and eliminating systematic errors in the GPS data. The results of these analyses will be used to devise improved strategies for data analysis and velocity estimation in order to achieve the highest possible precisions and accuracies necessary to resolve slow deformations. Dr. Davis will oversee all activities performed at the Smithsonian Astrophysical Observatory (SAO).

Dr. Richard Bennett will analyze the GPS data, including the development of software to manage the data flow. He will determine the Yucca Mountain crustal deformation field. He will also interpret data statistics, and assess the quality of the parameter estimates every day to ensure the strongest possible solutions. He will combine the geodetic solutions from the proposed Yucca Mountain geodetic network with geodetic solutions from other continuous GPS networks in order to strengthen daily position estimates, putting all of the results in a common, stable reference frame. The GPS site velocities will be estimated from these combined solutions. An important component of Dr. Bennett's analyses will be the determination of the local pattern of strain accumulation and interpretation vis-a-vis existing geological and geophysical measurements.

A dedicated data technician (computer specialist) will routinely perform the following tasks: (1) software development and maintenance; (2) daily data management including data flow, disk cleanup, backups, archiving; and (3) daily quality control and trouble shooting. A combination of automated software and vigilance are required to assure steady remote data downloads. A significant amount of time will also be required simply to archive data and manage disk space. Disk space consumption from a single day's tasks for a ~20 station continuous network is of the order of 200 Mbytes, compressed. One day per week backups to CD ROM and tape cartridge, followed by careful disk cleaning, are required to make space for incoming data and their timely analysis. This procedure is only partially automatic. Moreover, although we have developed and road-tested all software to be used for automated download and number crunching procedures, the performance of all programs must be checked carefully every day. We anticipate that manual data downloads and other procedures requiring remote communications to the sites will sometimes be necessary based on our experience with other continuous GPS networks. On occasion, GPS engineers will need to be dispatched to repair malfunctioning sites. Remote downloads and other testing from the SAO will usually need to be coordinated to coincide with these station visits. Transfer of data products from the Scripps Orbit and Permanent Array Center also requires manual assistance on occasion. A careful log of site visits, equipment and firmware changes, apparent site location changes, etc, for each station will be recorded, with changes relevant to the estimation of station velocities implemented as needed.

Budget Justification
Smithsonian Astrophysical Observatory

Salaries.

We request partial salary support for Dr. James Davis, who will devote a total of two and one half months per year to this research. His primary tasks will include error analyses of the GPS time series and the development and application of statistical tests. The techniques to be developed will involve principal component analyses, maximum likelihood methods. and other methods and will be aimed at identifying and eliminating systematic errors in the GPS data. The results of these analyses will be used to devise improved strategies for data analysis and velocity estimation in order to achieve the highest possible precisions and accuracies necessary to resolve slow deformations. Dr. Davis will oversee all activities performed at the Smithsonian Astrophysical Observatory (SAO). The following management plan is based on our two years of experience with the 18 station northern Basin and Range (NBAR) continuous GPS network.

Management plan for J. Davis

Task	Hours per week	Months per year
Error assessment	5	1.4
Statistical tests	4	1.2
Supervisory tasks	1	0.4
Totals	10	3.0

We request partial salary support for Dr. Richard Bennett, who will devote a total of four months per year to this research. His primary tasks will include software development and GPS data analysis with the objective of the determination of crustal deformation with the highest possible precision. Interpretation of data statistics, and daily assessment of the quality of the parameter estimates will be required to ensure the strongest possible solutions. Geodetic solutions from the proposed Yucca Mountain geodetic network will be combined with geodetic solutions from other continuous GPS networks in order to strengthen daily position estimates, putting all of the results in a common, stable reference frame. These data combinations must be performed manually to assess compatibility among the different geodetic solutions. GPS site velocities will be estimated from these combined solutions. The final step in the analyses will be the assessment of the reliability of daily position estimates and site velocities (see above). An important component of our analyses will be the determination of the local pattern of strain accumulation and interpretation vis-a-vis existing geological and geophysical measurements. The following management plan is based on our two years of experience with the NBAR continuous GPS network.

Management plan for R. Bennett

Task	Hours per week	Months per year
Daily analyses of raw GPS observations	4	1.2
Combination of geodetic solutions	4	1.2
Estimation of GPS site velocities	4	1.2
Geophysical interpretation	1	0.4
Totals	13	4.0

We request salary support for a dedicated data technician (computer specialist), who will dedicate six months per year to this research. She or he will routinely perform the following tasks: (1) software development and maintenance; (2) daily data management including data flow, disk cleanup, backups, archiving; and (3) daily quality control and trouble shooting. A combination of automated software and vigilance are required to assure steady remote data downloads. A significant amount of time will also be required simply to archive data and manage disk space. Disk space consumption from a single day's tasks for a ~20 station continuous network is of the order of 200 Mbytes, compressed. One day per week backups to CD ROM and tape cartridge, followed by careful disk cleaning, are required to make space for incoming data and their timely analysis. This procedure is only partially automatic. Moreover, although we have developed and road-tested all software to be used for automated download and number crunching procedures, the performance of all programs must be checked carefully every day. We anticipate that manual data downloads and other procedures requiring remote communications to the sites will sometimes be necessary based on our experience with other continuous GPS networks. On occasion, GPS engineers will need to be dispatched to repair malfunctioning sites. Remote downloads and other testing from the SAO will usually need to be coordinated to coincide with these station visits. Transfer of data products from the Scripps Orbit and Permanent Array Center also requires manual assistance on occasion. A careful log of site visits, equipment and firmware changes, apparent site location changes, etc, for each station will be recorded, with changes relevant to the estimation of station velocities implemented as needed. The following management plan is based on our two years of experience with the NBAR continuous GPS network.

Management plan for Data Technician

Task	Hours per week	Months per year
Software development and maintenance	3	0.9
Data download	6	1.8
Data backup and archiving	8	2.4
Record-keeping and trouble shooting	3	0.9
Totals	20	6.0

We request partial salary support for an administrative assistant. The tasks include salary administration, purchasing, manuscript preparation, budget preparation, and other miscellaneous administrative tasks.

Note that no salary support is requested for the period 6/1/98–9/30/98 as no data will have been collected. Effort will increase by 50% during the period 10/1/01–5/31/02, on the other hand, to accommodate anticipated additional work associated with the completion of the project such as the production of the final velocity and crustal strain fields including a summary of statistics, the writing of final reports, and the final archival of data and data products.

Travel.

Funds are requested for travel to Caltech for one week per year to collaborate with the P.I. Dr. Brian Wernicke.

Equipment.

Our two years of experience with the 18 station NBAR GPS network indicates that downloading and processing data from a ~20 station continuous GPS requires a dedicated high speed workstation, two modems, and enough on-line storage space to accommodate roughly 200 Mbytes of data per day in addition to a large amount of disk space required to analyze these data. We therefore request funds for one 360 MHz SUN Ultra workstation for data downloads and analyses. We request funds for a total of four 23 Gbyte hard disks, two of which will not be necessary until after the first period. These additional disks will be needed to accommodate data build-up. The budget amounts for these items reflect the significant educational discount available to SAO through Harvard University Technology Product Center.

Materials.

We request funds for a data backup device such as a CD-ROM recorder, as well as CD-ROMs and tapes for archiving of the all data and analysis products. We also request funding for a fireproof safe in which to store backups.

Communications and transportation.

We request a small amount of funds to cover phone charges and FedEx shipping charges.

2/9/98

DRAFT DISCLAIMER

This contractor document was prepared for the U.S. Department of Energy (DOE), but has not undergone programmatic, policy, or publication review, and is provided for information only. The document provides preliminary information that may change based on new information or analysis, and is not intended for publication or wide distribution; it is a lower level contractor document that may or may not directly contribute to a published DOE report. Although this document has undergone technical reviews at the contractor organization, it has not undergone a DOE policy review. Therefore, the views and opinions of authors expressed do not necessarily state or reflect those of the DOE. However, in the interest of the rapid transfer of information, we are providing this document for your information.

DRAFT DISCLAIMER

Patterson
Deb

TRW

TRW Environmental Safety Systems Inc.

1261 Town Center Drive
Las Vegas, NV 89134
702.295.5400

QA: N

Contract #: DE-AC01-91RW00134
LV.NEPO.LRH.01/99-034
January 4, 1999

Dennis R. Williams
Deputy Assistant Manager for Licensing
U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

Dear Mr. Williams:

Subject: Thermal Test Progress Report No. 1

I am pleased to transmit herewith the Thermal Test Progress Report No. 1 which is the first of a series of informal reports to be prepared every three months. This report has been prepared following the Sixth Thermal Test Workshop held at Livermore in October 1998. These progress reports are intended to help communicate the progress of the in-situ thermal tests, are not a Level 4 or 3 baseline commitment and should be considered draft in nature. Therefore, they are not subject to the provisions of the CRWMS M&O YAP 30.63 (Submittal, Review, and Acceptance of Deliverables) and should not be used in support of/or cited in QA activities.

Should you have any questions, please feel free to contact Robin Datta of my staff at (702) 295-5741 or me at (702) 295-5604.

Sincerely,

Larry R. Hayes

Larry R. Hayes, Manager
Natural Environment Program Operations
Management and Operating Contractor

cc:
R. E. Spence, DOE/YMSCO, Las Vegas, NV
R. L. Patterson, DOE/YMSCO, Las Vegas, NV
Deborah Barr, USGS, Las Vegas, NV
M. T. Peters, M&O, Las Vegas, NV

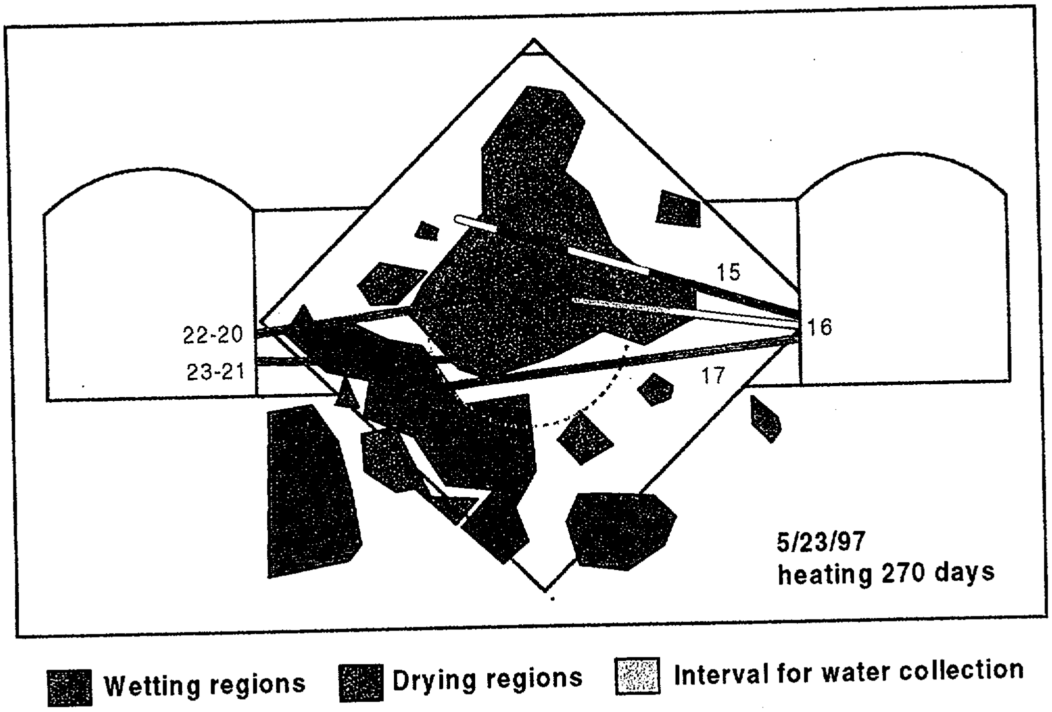


Figure 2.2-2 Zones of relative drying nd wetting after 270 days of heating in the SHT, as observed from ERT and Neutron measurements.

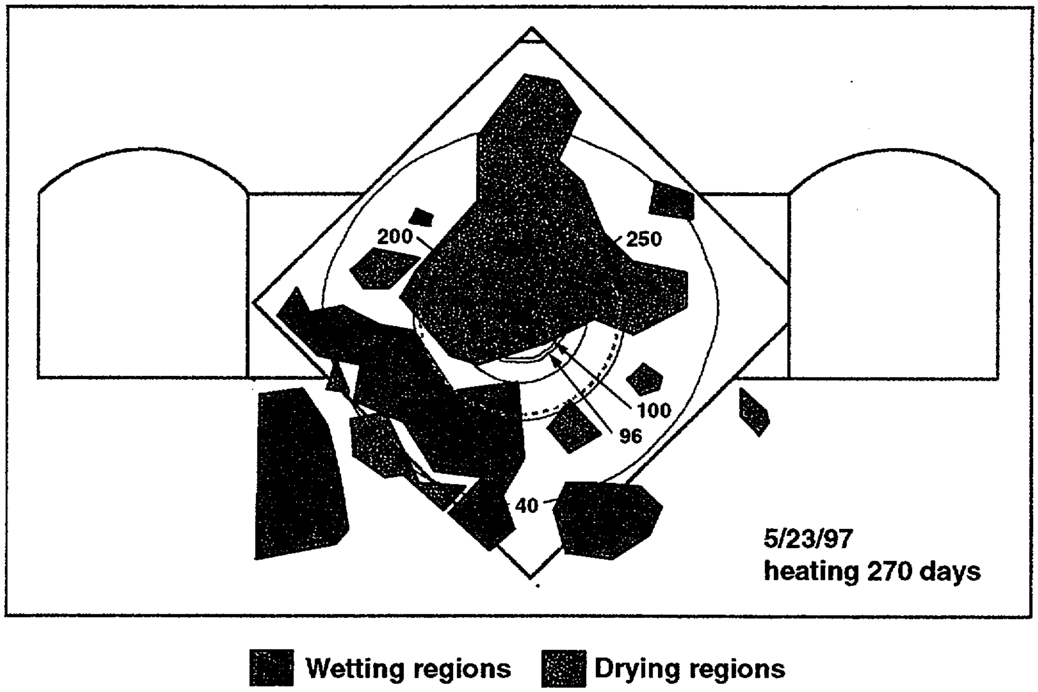


Figure 2.2-3 Comparison of relative drying and wetting regions with predicted temperature distribution at end of heating phase of SHT

3 LARGE BLOCK TEST

The Large Block Test (LBT), located at Fran Ridge south of Yucca Mountain, is the second in-situ thermal test conducted for the Yucca Mountain project. It is a test with controlled boundary conditions to evaluate the coupled thermal-mechanical-hydrological-chemical (TMHC) processes in the nearfield rock of the proposed repository. Specifically, the LBT is expected to help us understand the dominant heat transfer mechanism, condensate refluxing, relationship between boiling point isotherm and the drying of the rock mass, rewetting of the dry-out zone following the cool-down of the block, displacement in fractures, and rock–water interaction. The LBT will evaluate the corrosion/oxidation potential of coupons of candidate waste package materials. The LBT will also investigate the survivability and migration of the local microbes in a heated environment. The current status of the test, and the temperature, neutron logging results, and the microbial observations obtained so far are discussed in the rest of this section.

Description of the LBT

An outcrop area at Fran Ridge was selected because of its suitable rock type and accessibility. A 3 x 3 x 4.5 m block of nonlithophysal Topopah Spring tuff was isolated at Fran Ridge. Instruments and heaters were installed within and on the surface of the block. The instruments installed in the block included resistance temperature devices (RTD) to measure temperatures, electrodes to conduct electrical resistivity tomography (ERT), Teflon liners for the neutron logging in boreholes, Humicaps to measure relative humidity, pressure transducers to measure gas phase pressure, conventional and optical multiple point borehole extensometers (MPBX) for measuring displacements along boreholes, fracture gauges mounted across fractures on the block surface to monitor fracture deformation, Rapid Estimation of K and Alpha (REKA) probes to measure in-situ thermal conductivity and diffusivity, and visual observation of the drainage of water near the bottom of the block. Coupons of waste package material and introduced material were placed within the block to study the effect of the heated environment on the materials. Labeled local microbes were introduced back into the block to study their survivability and migration. The temperature measurements included the spatial and temporal variation of the temperature in the block and the thermal gradient on the block surfaces. One heater of 450 Watts was installed in each of the five horizontal heater holes at about 2.75 m below the block top. A heat exchanger was installed to control the temperature on the block top. A layer of RTV and Viton were installed on the block sides to minimize moisture flux. Three layers of insulation materials (Ultratemp, fiberglass building insulation, and Reflectix) were installed on the outside of the moisture barrier. All of the instrument holes were sealed either by cement grout, packers, or an RTV/Teflon membrane. Straps were used to stabilize the block and insulation during the test. Figure 3-1 shows a schematic diagram of the block displaying borehole location, orientation and purpose.

To conduct the test, the block is heated from within to reach a temperature of 140°C at the heater horizon, and the heat exchanger is used to keep the top temperature at about 60°C. Temperatures will be maintained constant for at least one month, after which the heaters will be turned off to start a cooling phase. Vapor is allowed to leave the top of the block. Background data were prior to heating. Data acquisition will continue throughout the test. The following parameters are measured continuously by an automated data acquisition system: heater power, temperatures, displacement by MPBX, relative humidity, pore gas pressure. Neutron logging, ERT, REKA, and optical MPBX are performed periodically. Air permeability and gas tracer tests were conducted before the heaters were energized, and will be performed again after the block is cooled. After the test, the block will be dismantled to examine for evidence of rock–water interactions, characteristics of the waste package material coupons and the introduced material coupons, and the survivability and migration of the microbes. Currently the data acquisition phase of the test has been completed. The data acquisition system was turned off on 9/30/98. Some of the instruments are being recovered for calibration and evaluation. Air permeability will be measured in the block. Coring and over-coring for samples for analyzing the rock-water interaction will be started soon.

The neutron results in NN6 agree with the observation of the migration of the microbes in the observation holes EO3, NO1, and NO2 below the heater horizon (Figure 3-1). The native microbes which were cultured to be double drug resistant, and placed in the heater holes, were detected in the observation holes during the heating phase. No microbes were observed after the end of the heating phase. It is likely that the microbes migrated from the heater holes along with the water that drained away in the fractures.

Summary

The data acquisition phase of the LBT has been completed. The LBT has provided experimental data of thermal-hydrological-mechanical processes. We observe a zone of dry-out at the heater horizon, and a condensate zone above it. Condensate refluxing is indicated by the temperature fluctuation, at least along boreholes TT1 and TT2. Water drainage away from the heater horizon was observed by the neutron logging and the microbial migration test. Core samples will be obtained from the block for studying rock-water interaction in the matrix and on the fracture surfaces. The thermal-hydrological results presented in this presentation will be incorporated with other observations, such as the displacement measurements, ERT, and the post-test analyses of the rock water interaction to enhance our understanding of the coupled TMHC processes.

Thermal-hydrological, thermal-mechanical, thermal-chemical, and the coupled processes models will be constructed to compare with the observed results. Through the comparison of the observations and the model calculations, the coupled TMHC processes will be better understood. The processes may be included in models used to predict characteristics of the near-field environment of a repository.

Large Block Test Instrument Holes

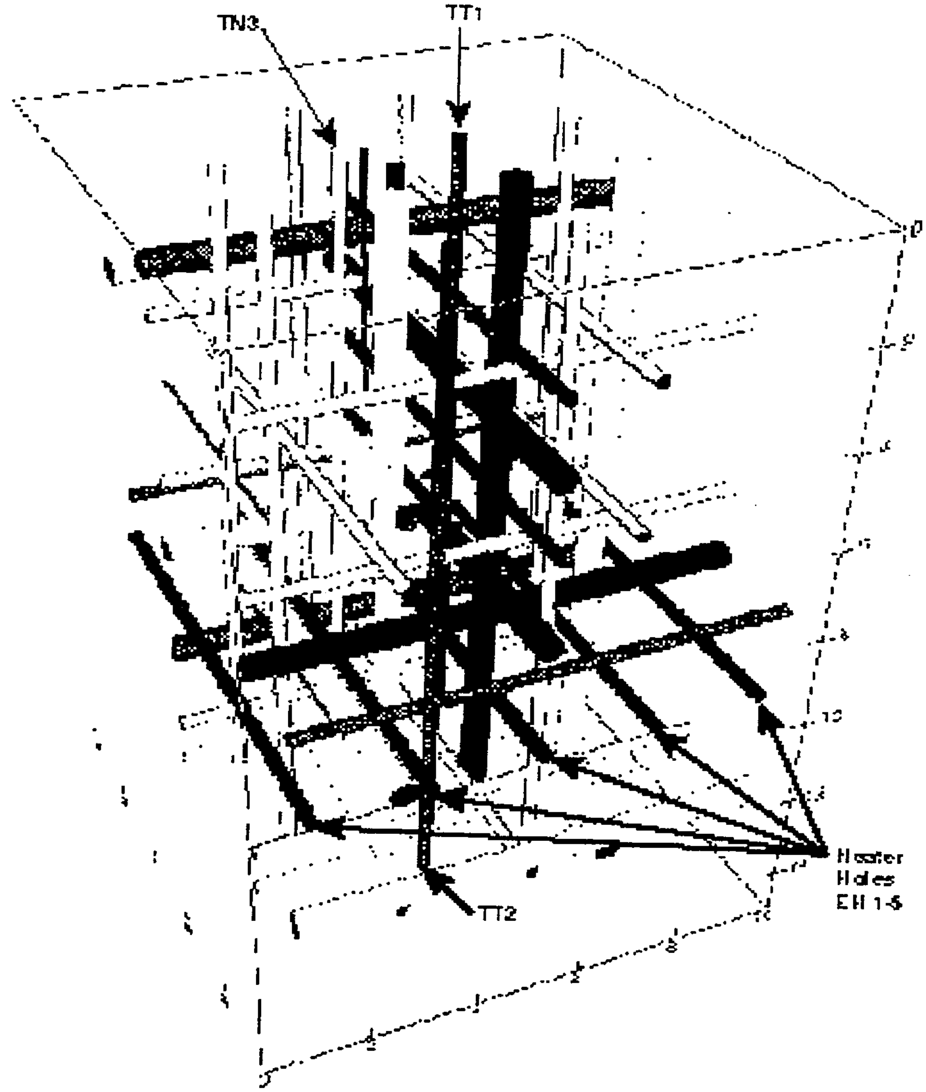


Figure 3-1. Schematic diagram of the large block with all of the boreholes. The color codes for the boreholes are: brown for RTD, yellow for MPBX, purple for packers, red for heaters, white for observation, green for neutron, black for REKA, orange for microbes, and blue for ERT.

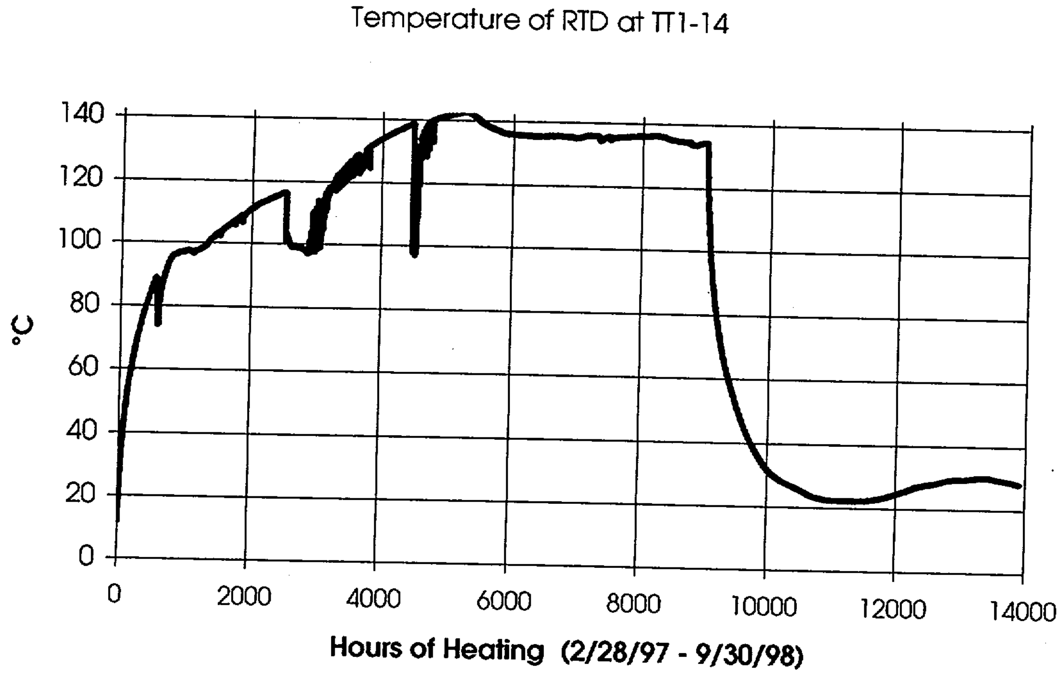


Figure 3-2. Temperatures at TT1-14 as a function of elapsed time.

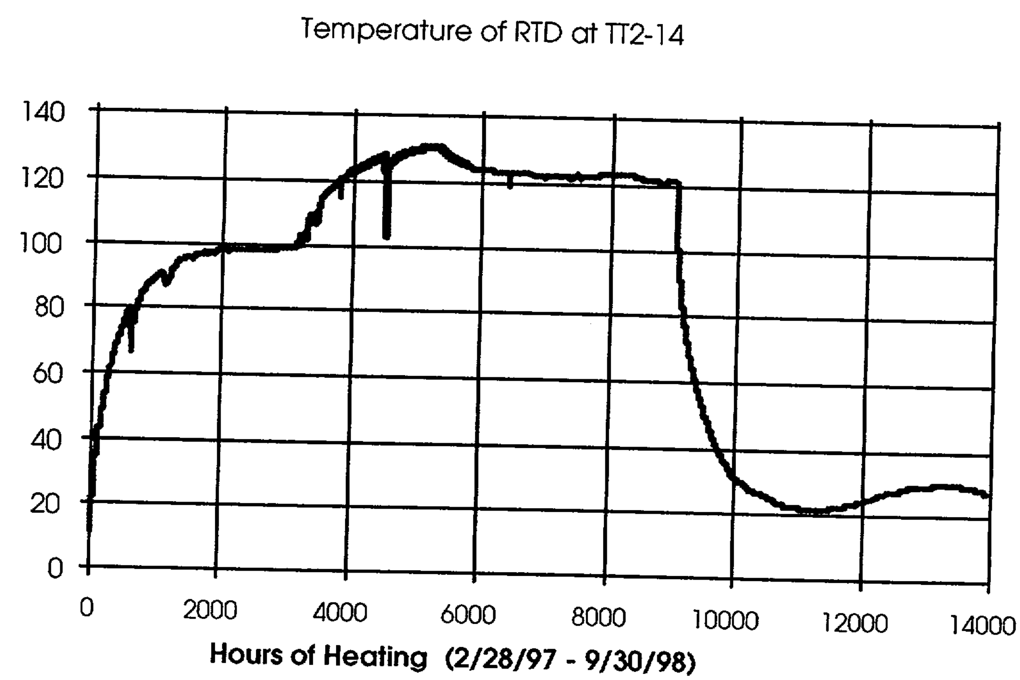


Figure 3-3. Temperatures measured at TT2-14 as a function of time.

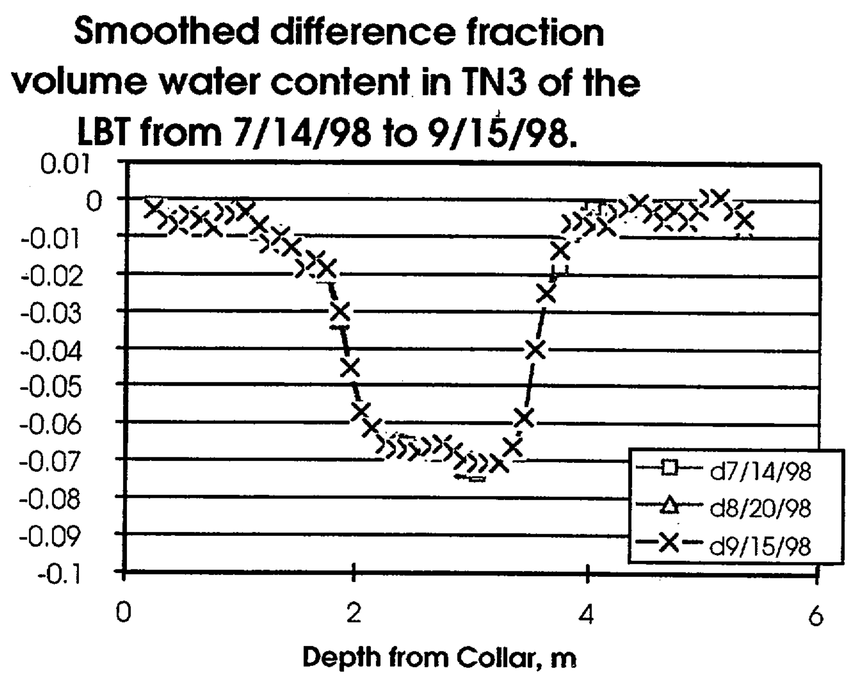


Figure 3-4. Smoothed difference fraction volume water content in TN3 as a function of depth from collar.

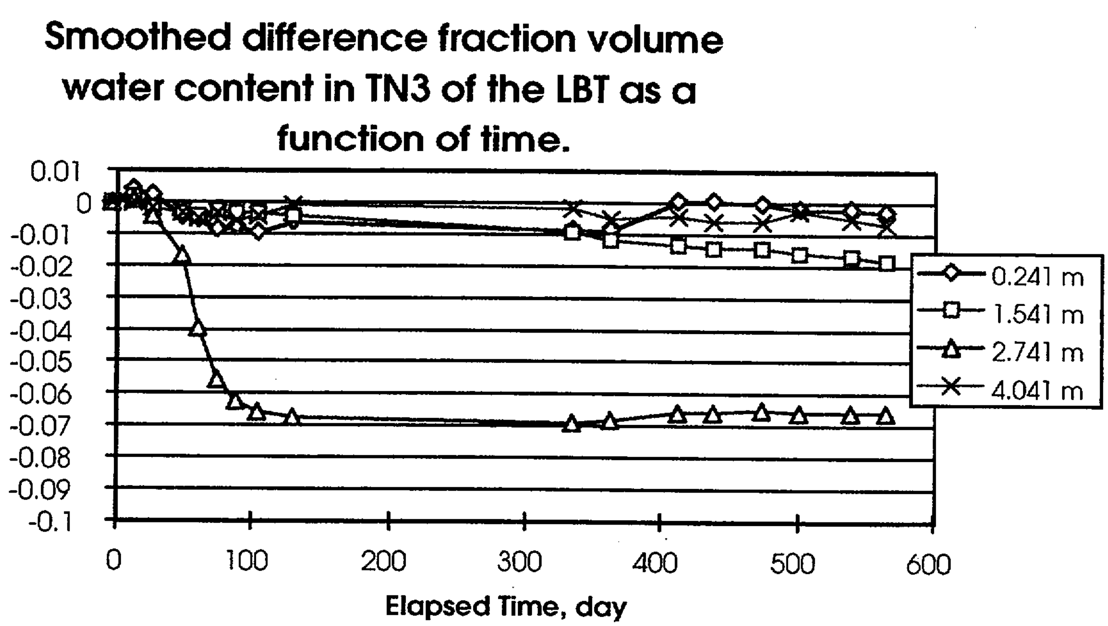


Figure 3-5. Smoothed difference fraction volume water content at four depths from collar in TN3 as a function of time.

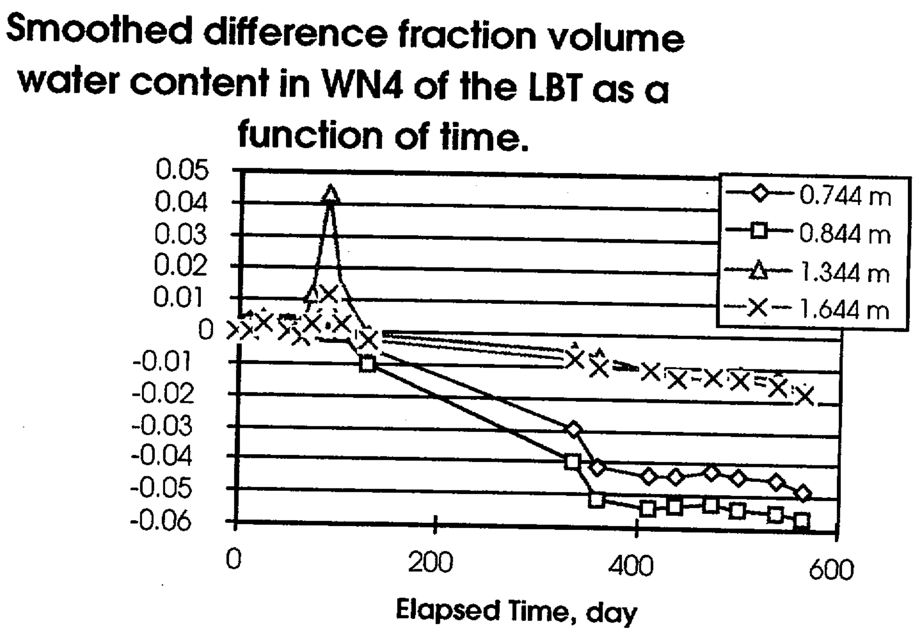


Figure 3-6. Smoothed difference fraction volume water content at four depths from collar in WN4 as a function of time.

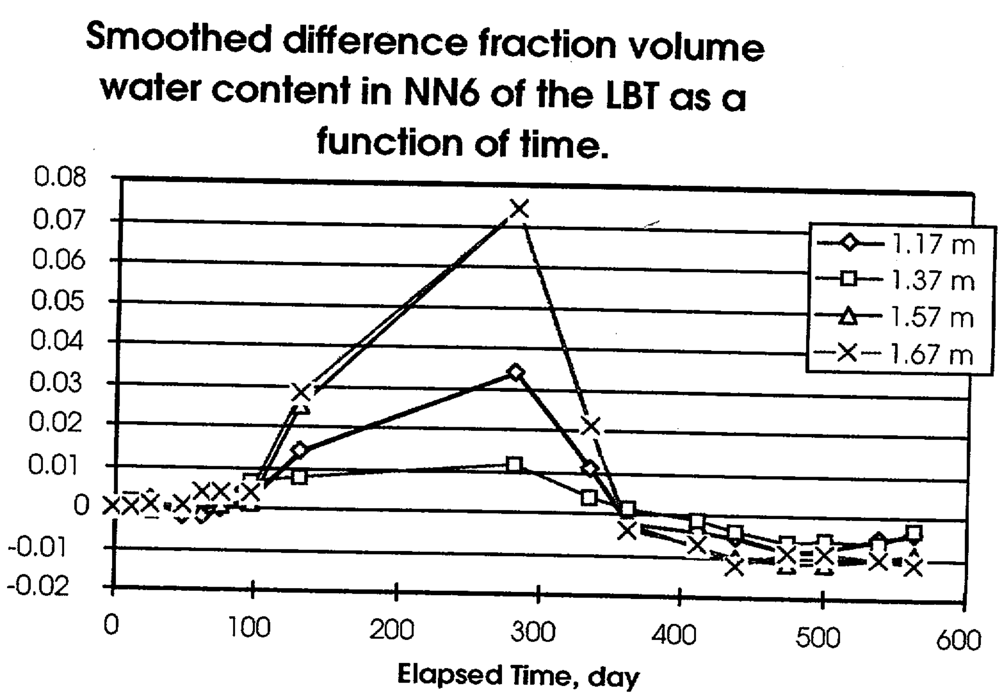


Figure 3-7. Smoothed difference fraction volume water content I at four depths from collar in NN6 as a function of time.

4 DRIFT SCALE TEST

The Drift Scale Test (DST), located in Alcove #5 in the ESF, is described in the report, "Drift Scale Test Design and Forecast Results", document # BAB000000-01717-4600-00007 REV 00 of July 16, 1997. The heating phase of the DST, initiated on December 3, 1997, is scheduled to continue for approximately four years to be followed by a cooling phase of similar duration. The "as-built" DST and the pre-heating baseline measurements are in the report, "Drift Scale Test As-Built Report", document # BAB000000-01717-5700-00003 REV 01 of July 1998. Test results until May 31, 1998 are presented and discussed in the report, "Drift Scale Test Progress Report #1", document # BAB000000-01717-5700-00004 REV 01 of November 1998.

4.1 POWER AND TEMPERATURE DATA

Heater power and temperature data from the start of measurements to September 30, 1998 are presented and discussed in this Section.

Power Data

Figure 4.1-1 illustrates the total power being supplied to all of the wing heaters and all of the canister heaters.. These total power data are Q measurements. The power being supplied to individual canister heaters and to individual wing heater elements are illustrated in Figures 4.1-2 and 4.1-3, respectively. These individual heater element power data are not Q measurements.

The wing heater power was fairly constant up until about day 185 (6/6/1998), when it dropped a few percent. This was a result of the loss of power to the inner and outer elements of wing heater 29. On day 211 (7/3/1998) the outer element of wing heater 26 failed. The power distribution to individual wing heater elements on day 301 (9/30/1998) is illustrated in Figure 4.1-4.

The canister heater power decreased from about 53 kW at the beginning of the test to about 51 kw on day 244 (8/4/1998), a drop of about 2%. From day 244 to 270 (8/30/1998) the power increased to about 53.5 kW. This increase is likely due to changes in the ventilation system just outside the Heated Drift, which were implemented on 8/4/1998. These changes resulted in increased airflow near the cables supplying power to the canister heaters. This increased airflow likely cooled the cables, thereby decreasing the cable resistance. Decreased resistance increased the current flow in the heater circuit, thereby increasing the power to the heaters.

Thermal Data from the Heated Drift

Figures 4.1-5, 4.1-6 and 4.1-7 illustrate the temperatures on the canister heaters, in the air in the Heated Drift and on the walls of the Heated Drift, respectively. By day 301 (9/30/1998) the canisters had reached temperatures of about 150 °C while the air and wall surface temperatures were about 135 °C. For each of these three data sets, the temperatures started out at about 30 °C just prior to the start of the test. When the heaters were activated, the temperatures rose very rapidly at first, but then the rate of increase of temperature decreased with time up until about day 130 (4/12/1998). From day 130 to day 239 (7/30/1998) the temperatures increased nearly linearly. The reason the rate of temperature increase stabilized is likely due to the presence of the wing heaters; without them, the rate of temperature increase would likely have continued to decrease. On day 239, there was a drop in the canister, air and surface temperatures of about 5 °C. This was a result of cool, ambient air being forced into the Heated Drift through a hole in the bulkhead. This condition persisted for about 5 days. When the hole was closed, the temperatures started to increase again. It is interesting to note that after the hole was sealed the rate of temperature increase, while still nearly constant, appears to be slightly less than the rate of temperature increase prior to the incident with the hole. The reason for this is not known. The air and surface temperatures in the Heated Drift indicate that by day 301 (9/30/1998), the middle part of the drift was about 5 or 6 °C warmer than the ends (Figures 4.1-8 and 4.1-9).

Figure 4.1-10 illustrates the air pressure and humidity measured inside the Heated Drift. These measurements are correlated. When the air pressure increases, relatively dry air from outside the Heated Drift if forced into the drift decreasing the humidity. During the time that outside air was being forced into the drift through the hole in the bulkhead there was a pronounced decrease in humidity in the Heated Drift, but no appreciable change in air pressure,.

Figure 4.1-11 illustrates the temperatures recorded by the temperature sensors mounted on the hot side of the thermal bulkhead. The pronounced changes in the temperature distribution on the bulkhead which occurred on day 239 were caused by changes in the thermal insulation on the outside of the bulkhead and in the ventilation system just outside the drift.

Rock Temperature

Figure 4.1-12 illustrates temperature contours on a vertical plane that is perpendicular to the axis of the drift and which intersects the drift at approximately its midpoint (Y = 23 m). The dots indicate the locations of the temperature sensors grouted into eight boreholes radiating out from the drift at this location. The contours in Figure 4.1-12 honor the data measured at these locations after 301 days of heating (9/30/1998). The warmest temperatures are measured near the wing heaters and surrounding the top of the Heated Drift. The region immediately below the drift is slightly cooler than the top of the drift because of the insulating effect of the concrete invert in the drift. Analysis of the contours in Figure 4.1-12 indicates that an area of approximately 160 m^2 is warmer than the boiling point of water (97°C). If it is assumed that the temperature distribution is identical all along the length of the 47.5 meter long drift, then approximately 7600 m^3 of rock has been heated to temperatures exceeding the boiling point. This estimate is likely slightly high since the cross sectional area above boiling likely decreases as the ends of the drift are approached. This tendency to overestimate the volume of rock above boiling is balanced somewhat however by ignoring regions of rock beyond the ends of the drift which are above boiling.

Figure 4.1-13 shows the temperatures observed after 301 days of heating (9/30/1998) in the four horizontal boreholes emanating from the Heated Drift. The data indicate that the rock adjacent to the wing heaters is warmer than the rock near the Heated Drift. This is because of the higher power output of the wing heaters as compared to the canister heaters in the drift. The temperatures near the wing heaters show two pronounced "humps", which correspond to the locations of the two wing heater elements deployed in each borehole. The data from the left side of the drift at Y=23 meters do not exhibit a noticeable "hump" associated with the outer wing heater since this hole is located midway between wing heaters 6 and 7 and the outer heating element of wing heater 7 is operating at only about 75% power. Three of the four temperature profiles exhibit a slight shoulder about 14 meters from the drift at a temperature corresponding to the boiling point of water. These are manifestations of a region of rock where water in the pores of the rock is boiling.

Figure 4.1-14 illustrates the temperature recorded by the temperature gage located at approximately X= -11 meters in borehole 160 (Y = 23 meters). The rock near this gage reached a temperature of about 96 °C 70 days after the start of the test. It remained near that temperature for more than 20 days, during which time the heat entering the rock near this location was devoted almost entirely to vaporizing water instead of to raising the temperature of the rock. After 20 days, all the water in the rock near this location had vaporized and the temperature started to increase again. By day 301 (9/30/1998) the rock near this gage had reached a temperature of 167 °C.

Figure 4.1-15 illustrates the temperatures measured by the gages in borehole 79 every 10 days since heater activation. This hole is oriented parallel to the axis of the Heated Drift at X = +9.5 meters. Near the bulkhead, it is located about 4 meters above the plane of the wing heaters but dips downward such that it is closer to the wing heaters at the bottom of the hole. The general warming with depth in the hole is due to the increasing proximity to the wing heaters with depth. What is noteworthy in this hole is that portions of the hole seem to develop positive temperature anomalies with respect to the rest of the hole. The most notable is located at around Y = 13 meters, where the temperatures begin to warm, as compared to rocks shallower and deeper in the hole, after about 130 days of heating. Less pronounced anomalies exist at Y = 24, 31 and 36 meters. These anomolously warm regions may be located near fractures where warm fluids are flowing upwards, away from the plane of the wing heaters located below the borehole. Also note how the rate of temperature increase slows dramatically as the boiling temperature is approached.

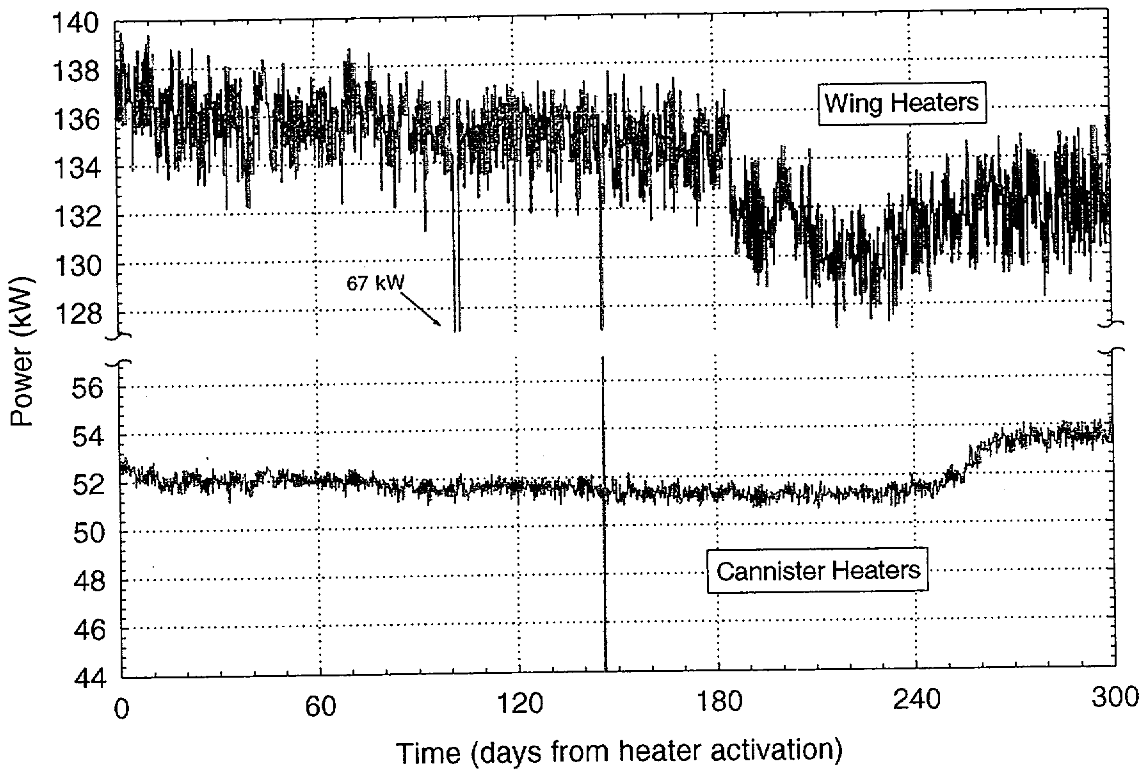


Figure 4.1-1 Heater Power – Qualified Measurements

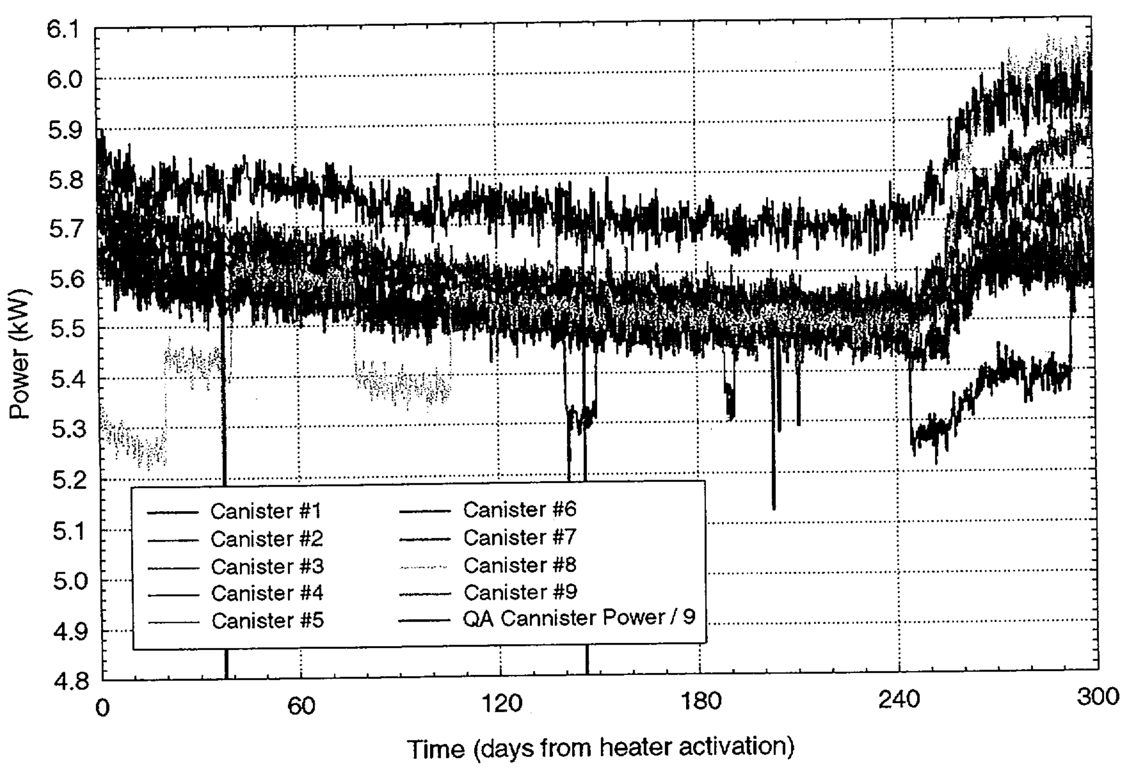


Figure 4.1-2 Canister Heater Power – Unqualified Measurements

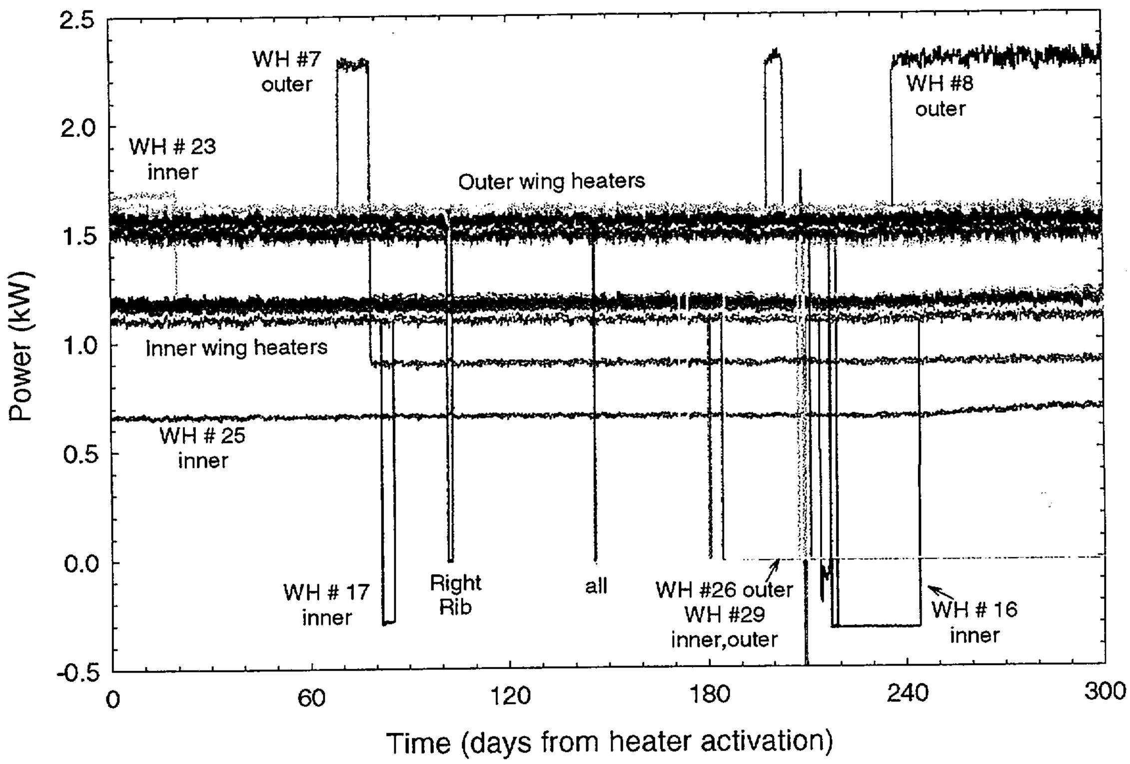


Figure 4.1-3 Wing Heater Power – Unqualified Measurements

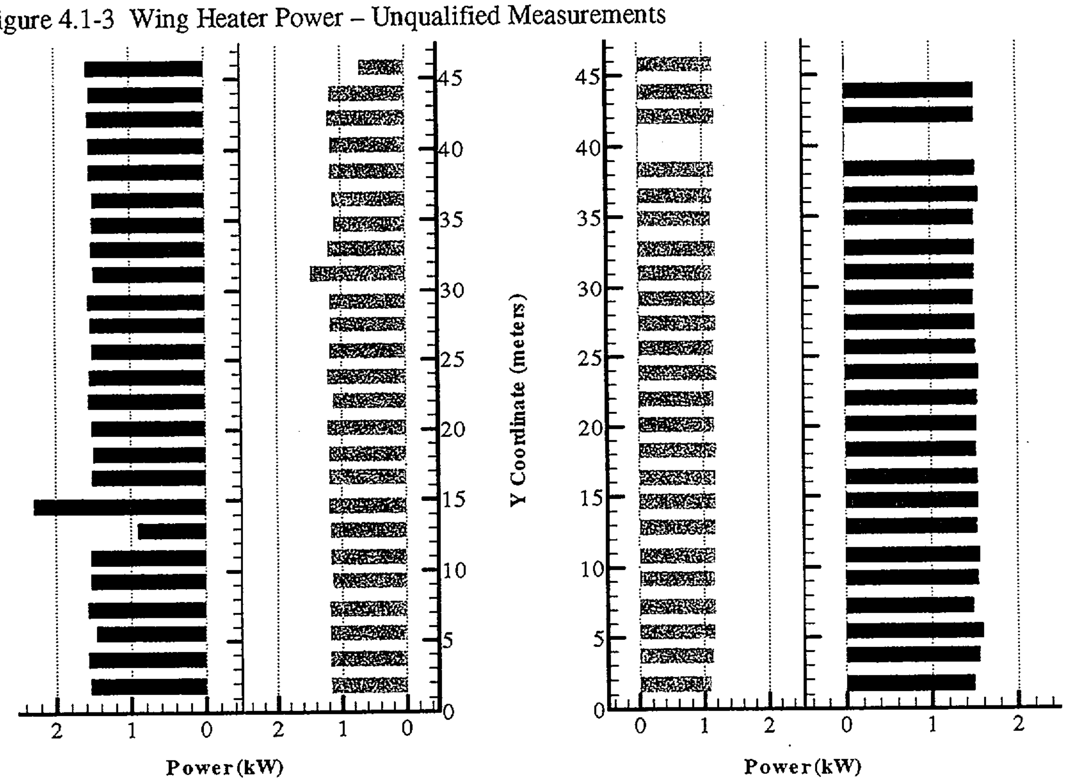


Figure 4.1-4 Wing Heater Power After 300 Days of Heating (9/30/1998).

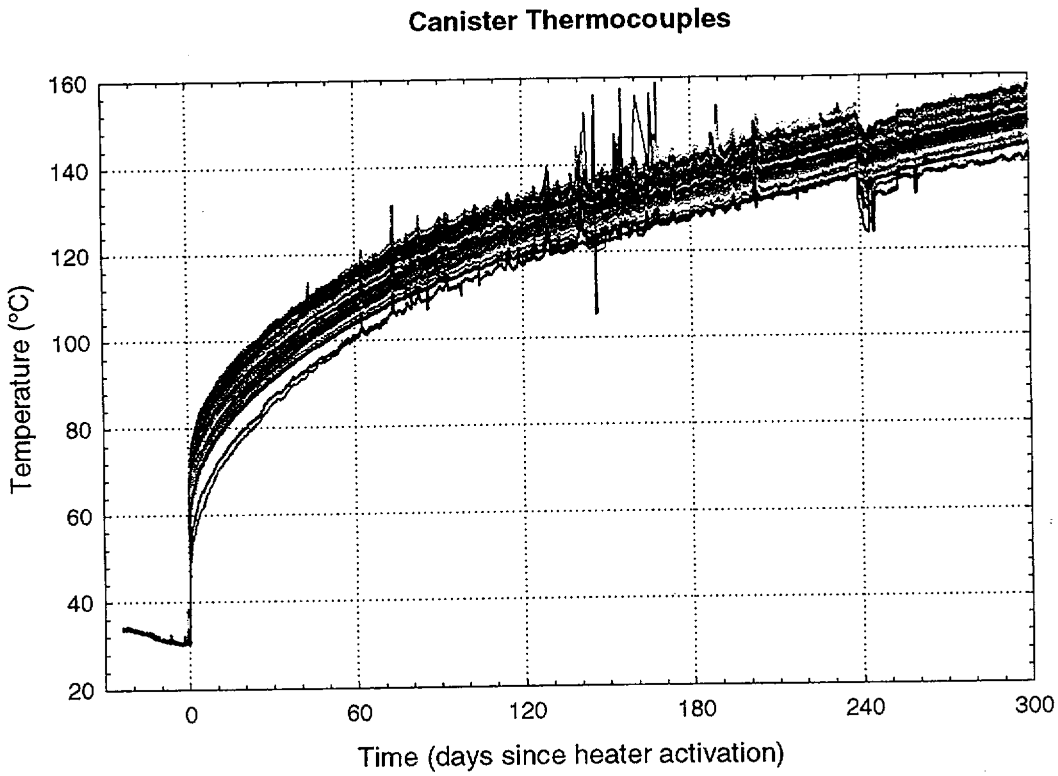


Figure 4.1-5 Canister Thermocouples

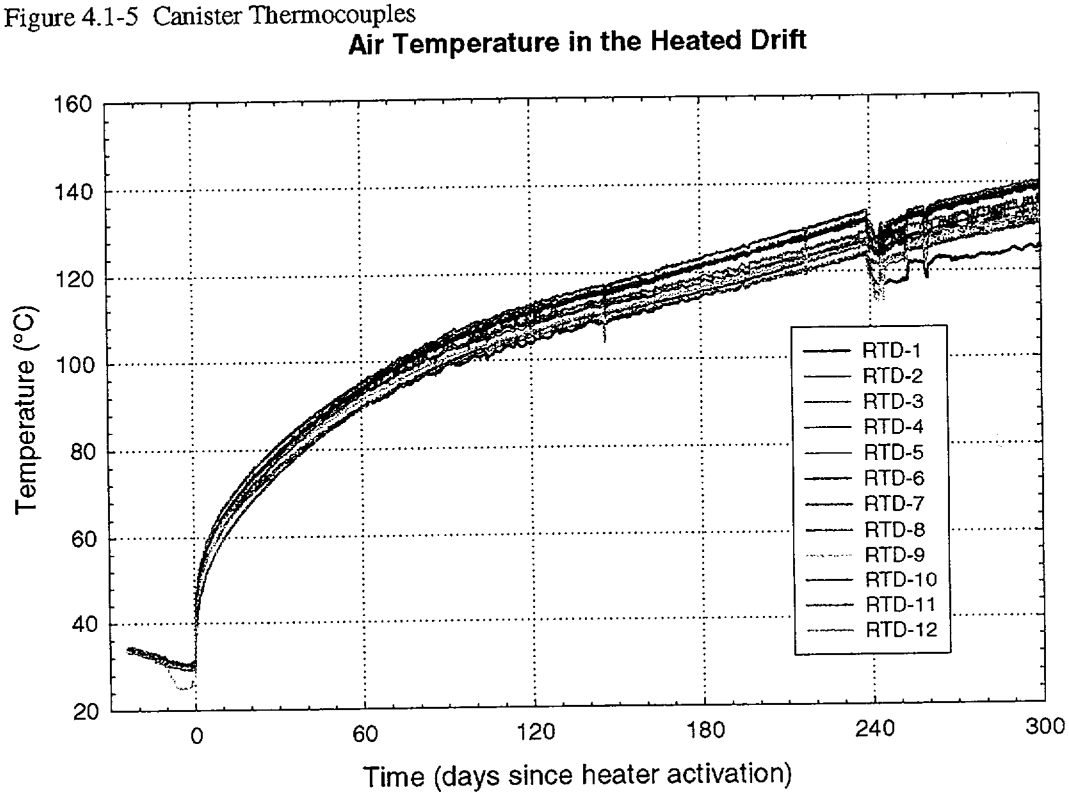


Figure 4.1-6 Air Temperature in the Heated Drift

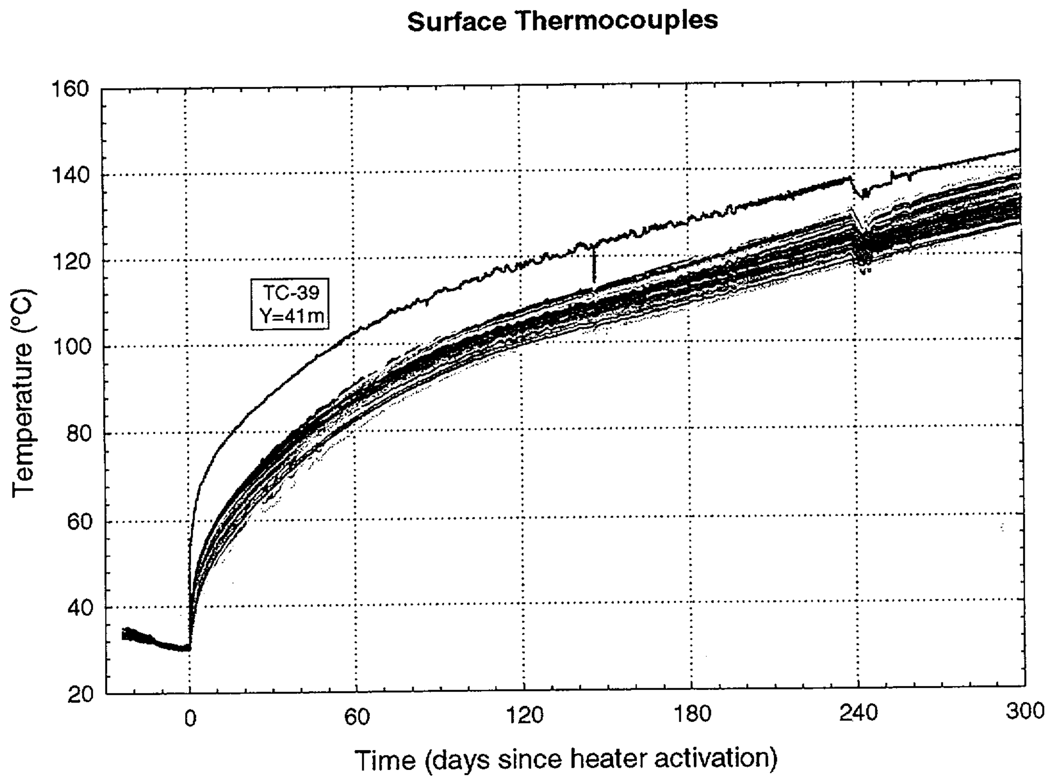


Figure 4.1-7 Surface Thermocouples

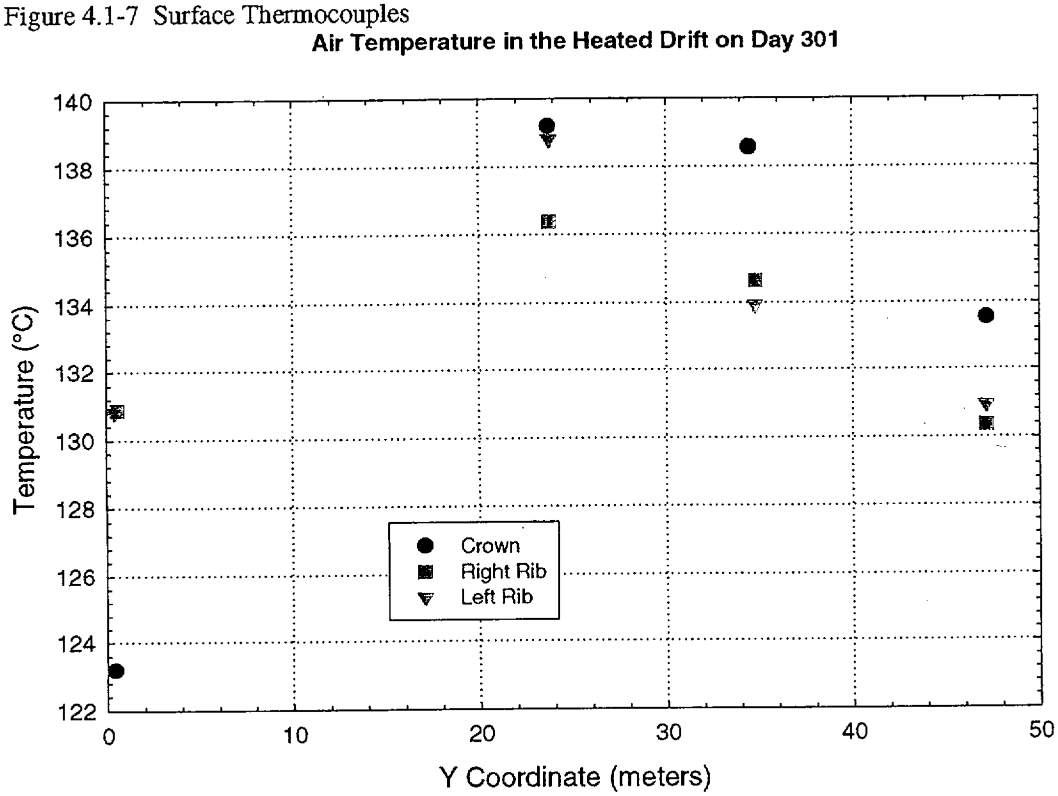


Figure 4.1-8 Air Temperature I the Heated Drift on Day 301

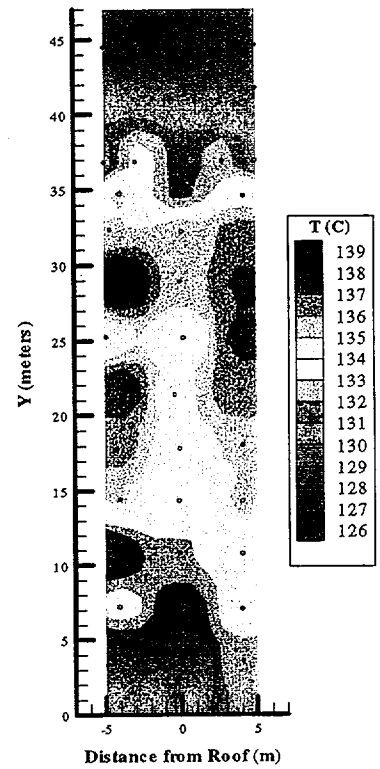


Figure 4.1-9 Temperature distribution on Wall of Heated Drift

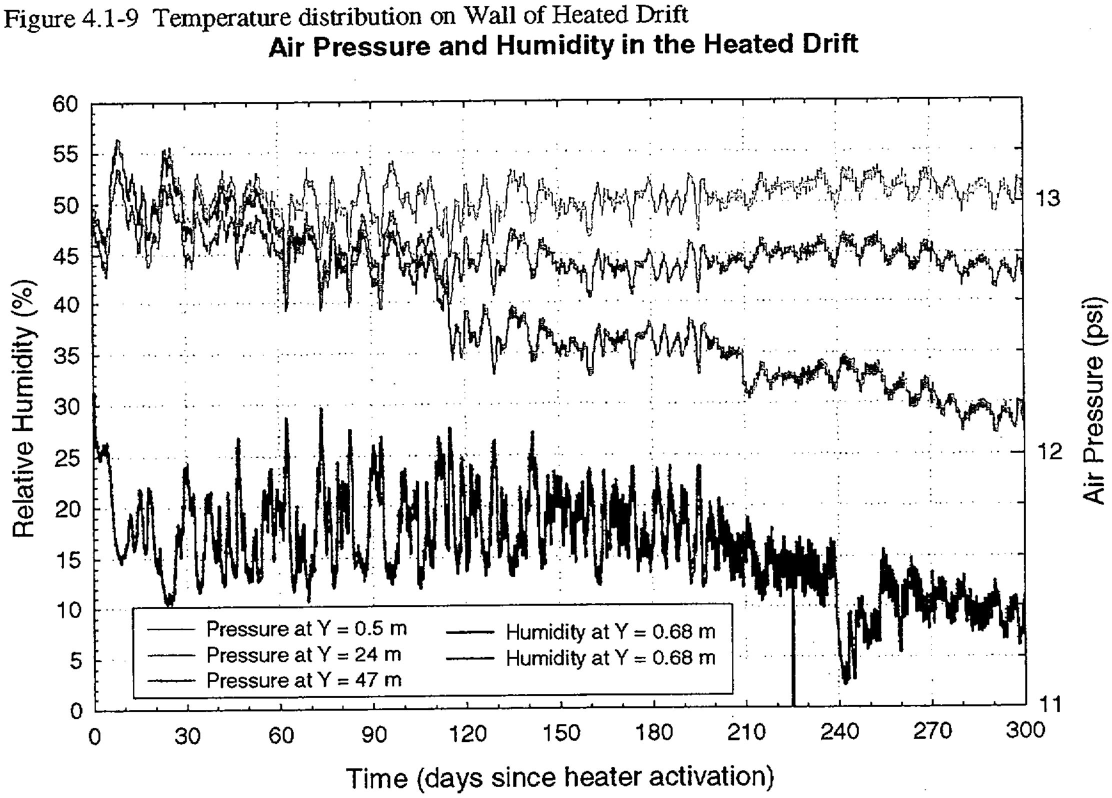


Figure 4.1-10 Air Pressure and Humidity in the Heated Drift

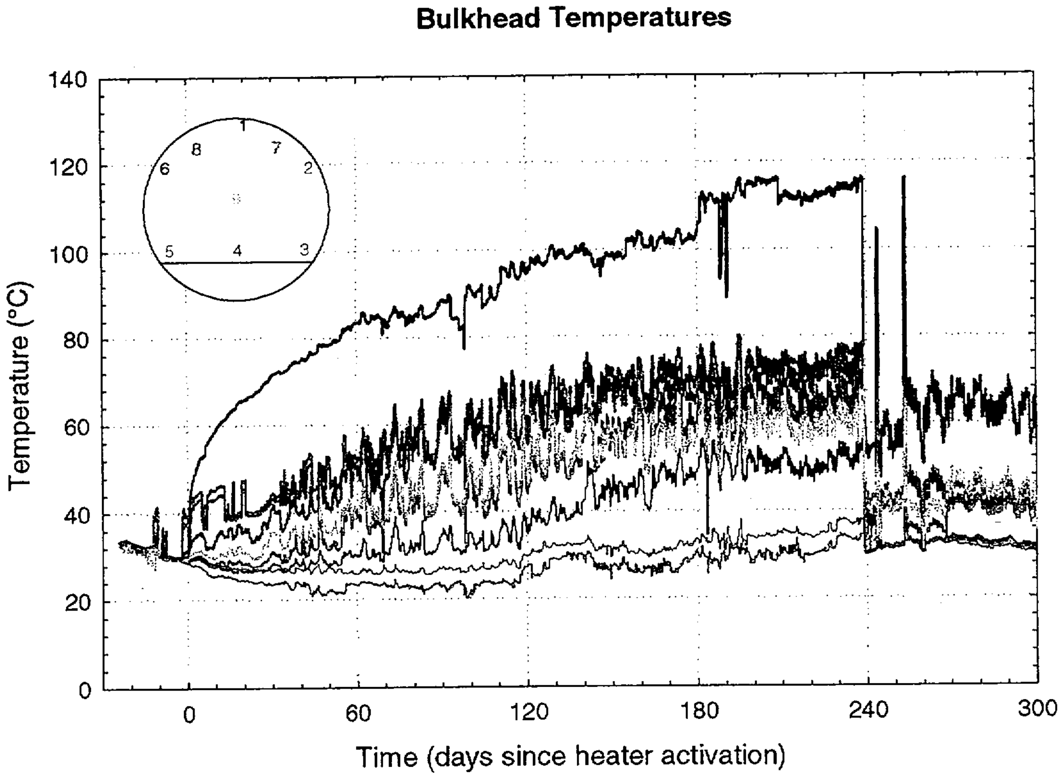


Figure 4.1-11 Bulkhead Temperatures

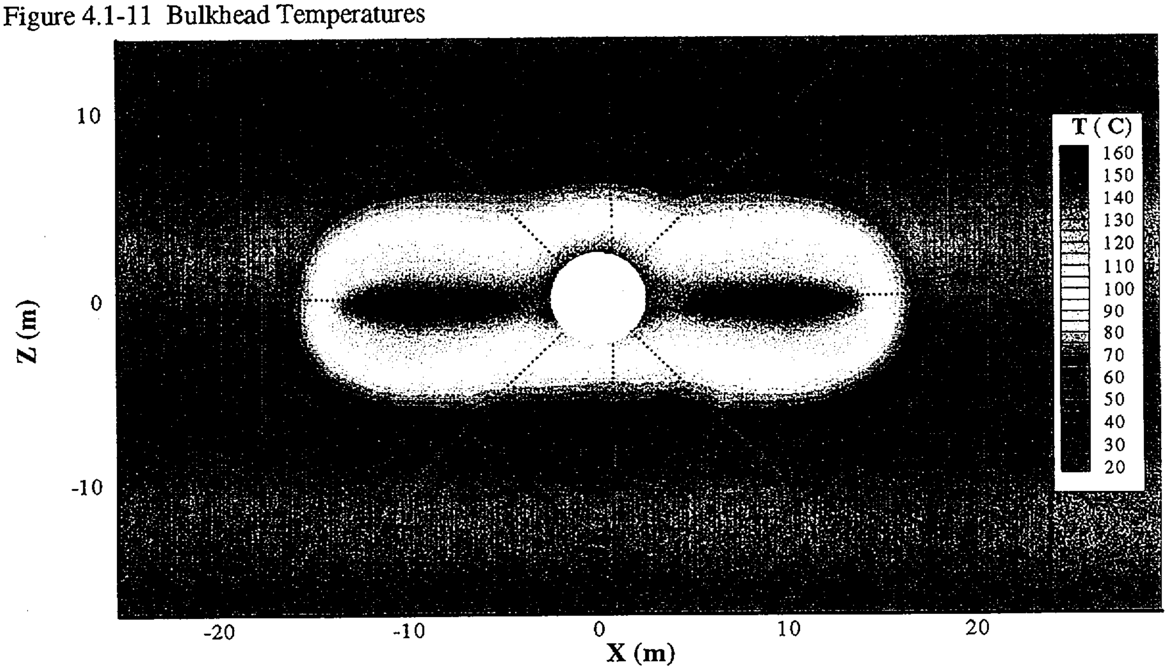


Figure 4.1-12 Temperature contours on the Vertical Plane at Y= 23 m After 301 Days of Heating

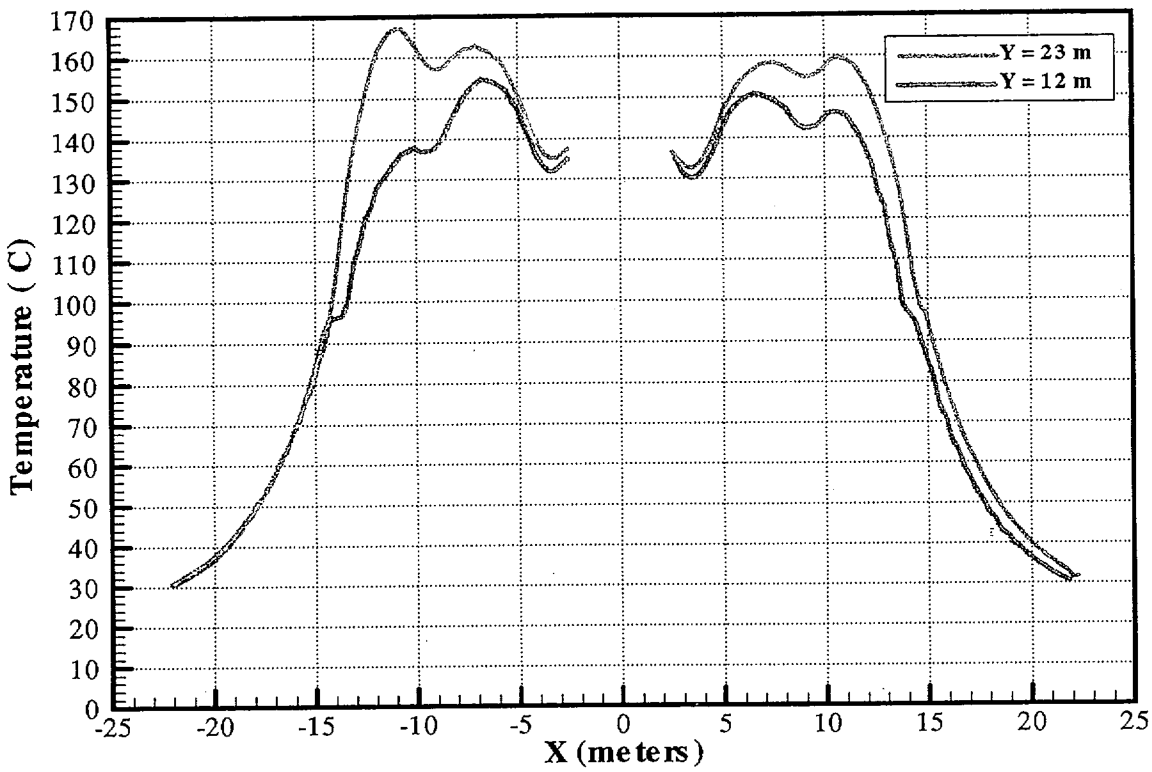


Figure 4.1-13 Temperatures in horizontal RTD Holes After 300 Days of Heating

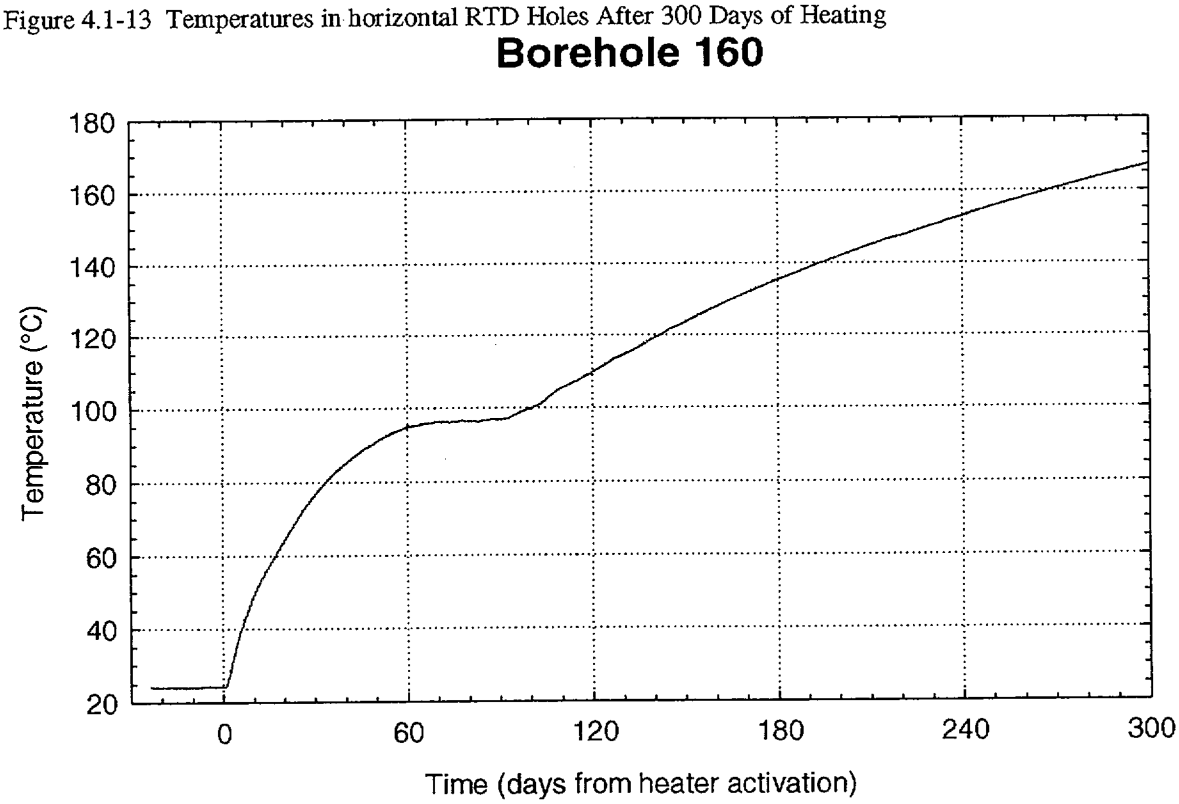


Figure 4.1-14 Borehole 160

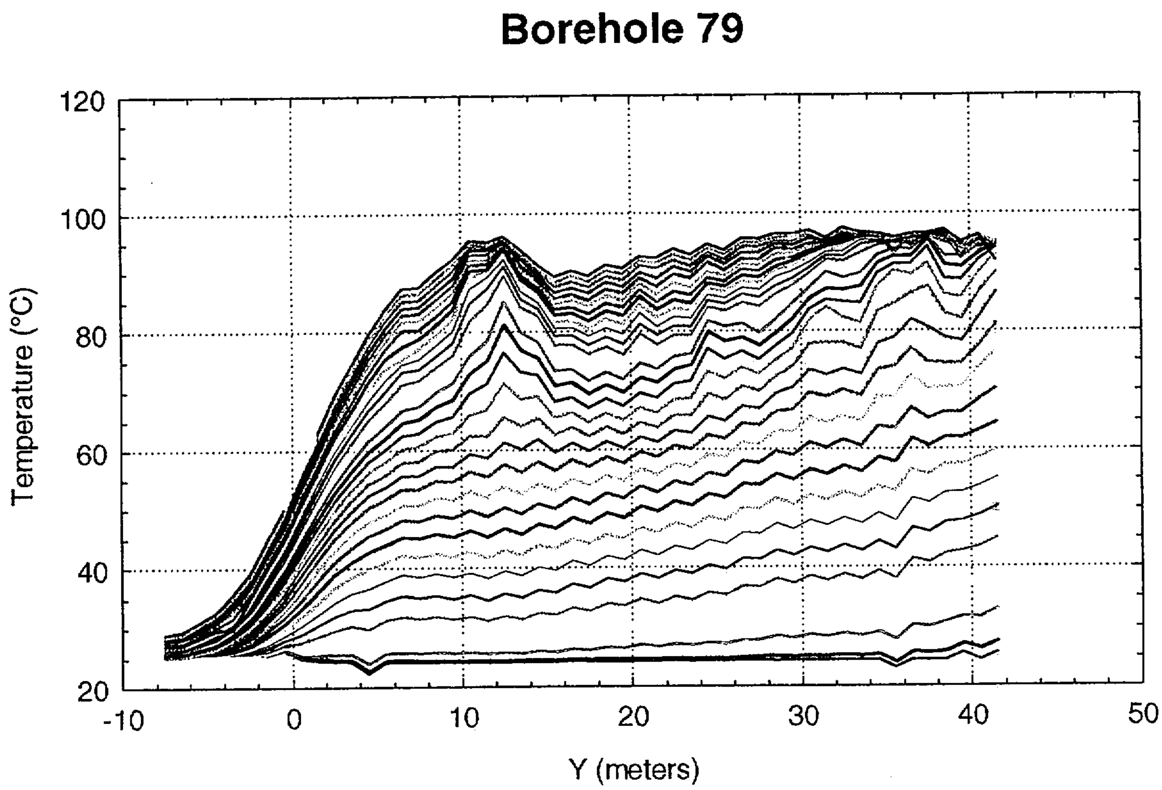


Figure 4.1-15 Borehole 79

4.2 Mechanical Measurements

One of the most significant events during the 3rd quarter time period was a change in the ventilation in the Thermal Test Alcove which caused a cooldown in the Heated Drift. According to the Test Coordination Office, on Thursday 7/30/1998 at approximately 1130 hours, the new Alcove #5 high power ventilation system was started. As per A/E Design Drawing BABFAA000-01717-2100-44110-00, the new system delivers approximately 20,000 cubic feet per minute (CFM) to a location about 10 feet from the Thermal Bulkhead. If conditions near the bulkhead exceed 98°F (37°C), a second duct delivers another 20,000 CFM until the temperature drops below this threshold. Sometime after the system was started on 7/30/1998, the insulation that plugs the hole in the bulkhead allowing the camera rail to pass through the bulkhead became dislodged. This provided an open conduit for a large quantity of ambient air to be forced into the Heated Drift. The Heated Drift experienced a cooldown as shown by the various temperature sensors in the drift. This hole was discovered the evening of Wednesday 8/5/1998 and re-sealed. Until the hole was sealed, the air temperature in the drift had dropped from around 272°F (133°C) on Thursday to around 259°F (126°C) on Wednesday.

Temperature changes resulting from the increased ventilation through the bulkhead were observed all the way to the deep end of the drift, where decreases of 2-5°C were observed on the surface thermocouples on the concrete liner.

Another problem with temperatures was found with the TCs along MPBX-1 (Borehole 81, the long borehole parallel to the drift axis on the north side of the drift). On June 19, all the temperatures in this borehole undergo a precipitous drop, with the TCs in the deep end of the borehole dropping as much as 10 °C. For about a month afterward, the temperatures apparently rise at a higher rate. Then on July 28, the temperatures drop again, to curves which seem to be what they would have been if they had risen according to the original rates.

The second drop in temperature near July 28th is most probably related to the high power ventilation system being turned on. The first drop around June 19th is more difficult to explain. The dates do not correspond to Plate Loading Test activities, so that may be eliminated as a cause. The TCO reports that no hardware or scan changes were made to the DST DCS during this month interval. The only potentially related event uncovered thus far is that the main ESF ventilation system was shut down at about 15:00 UTC (08:00 PDT) on June 20th for 48 hours for LBNL to conduct seismic testing/monitoring in the ESF. The Alcove 5 old ventilation system continued to operate as normal.

Mechanical Data

The behavior exhibited thus far by the MPBXs continues to be similar to the elastic model predictions, with the exception of MPBX-14, which demonstrates separation between the invert and liner. The deepest anchor (Anchor #4) for the MPBXs is progressing toward having the largest displacement from the collar. Most of the MPBX sensors are working well; however, MPBX-5, -7, and –11 have gone totally bad, and MPBX-3, -6, and -14 have gotten progressively noisier during the 3rd quarter.

Due to a problem with the revision of the scan software done on August 4th, the CDEX-1 and CDEX-2 data were not read properly by the DCS for the interval from 8/4/1998 until 9/25/1998. The raw data and Q Engineering readings do not exist for these sensors during this interval. After 9/25/1998 the readings are done the normal manner.

The strain gages placed on the concrete liner and on unconstrained concrete samples in the Heated Drift continue to show the combined effects of thermal expansion, dehydration-induced shrinkage, and mechanical stress imposed by the interaction of the concrete with the heated rock surrounding the drift. The results from the strain gages on the unconstrained samples exhibit behavior indicative of drying shrinkage due to dehydration, a phenomenon seen elsewhere in engineering literature. The cirumferential

Table 4.2-1. Comparison of Rock Mass Matrix Thermal Expansion

Test Name	Gage Length (m)	Average Temp./ Temp. Range (°C)	Coefficient of Thermal Expansion (10^{-6}/°C)
Single Heater Test	2.84	160	5.88
Single Heater Test	4.14	70	4.14
Single Heater Test	2.36	116	3.4
Drift Scale Test	7	25-50	1.65
Drift Scale Test	7	50-75	2.51
Drift Scale Test	7	75-100	3.25
Laboratory	0.1	25-200	~10

Figure 4.2-1. Increase in Thermal Expansion Above 200°C. Due to silica Phase Change

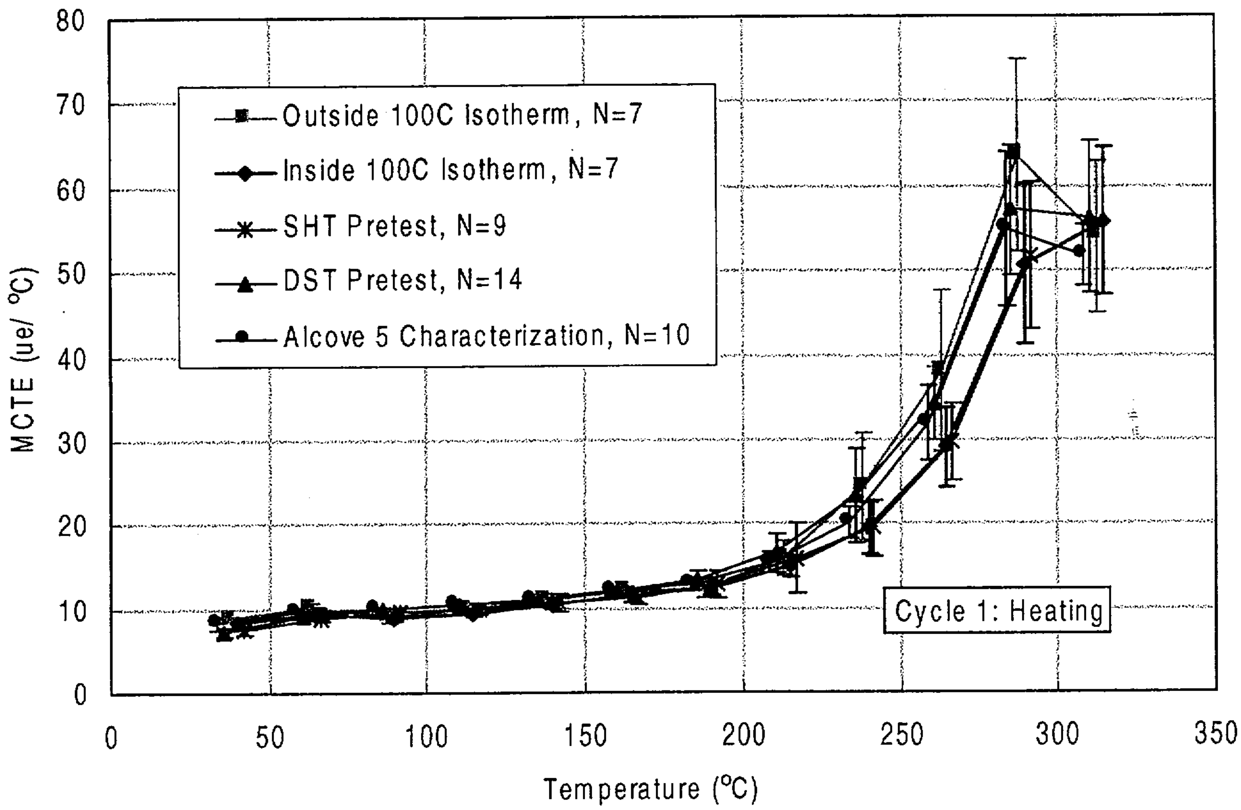
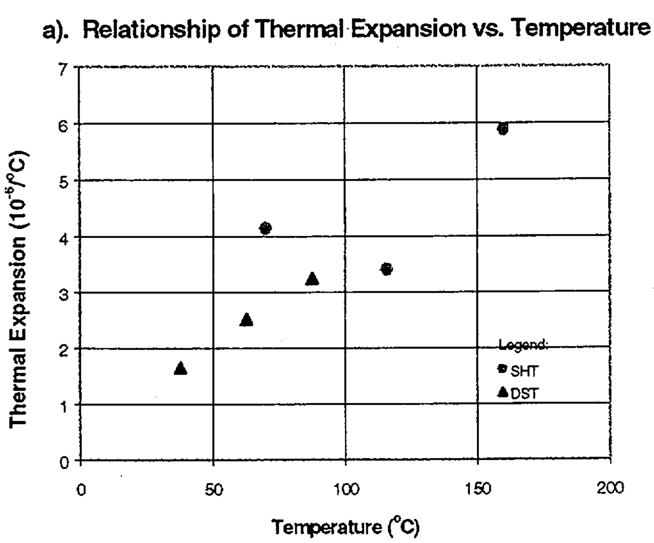
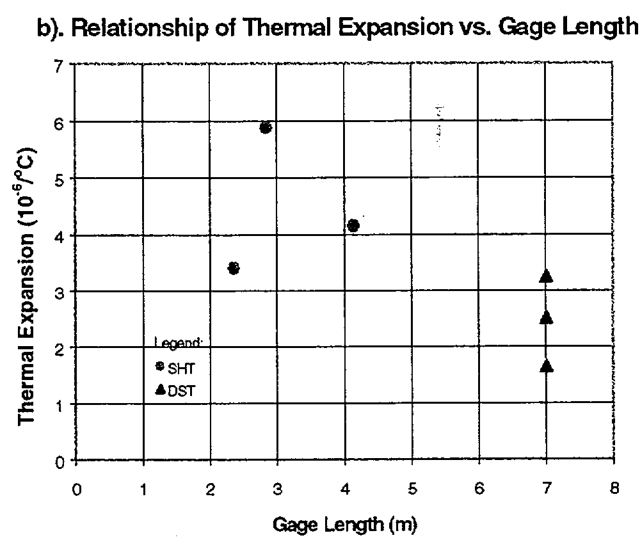


Figure 4.2-2. Relationship of Thermal Expansion vs. Temperature (a) and Gage Length (b)





4.3 Air-K and Gas Tracer Tests

Input to progress report on ESF thermal test, November, 1998
from Yvonne Tsang on
Hydrological measurements in the Drift Scale Test

The most prominent thermal-hydrological processes anticipated in the Drift Scale Test (DST) is the redistribution of moisture by vapor transport and subsequent condensation. Air injection tests in 4 consecutive zones in each of the twelve hydrology holes, carried out at approximately three month intervals, are intended to monitor the changes in liquid saturation in the fractures due to vaporization and condensation. In particular, results of the air injection tests are used to locate those zones where liquid saturation in the fracture has increased, thus giving rise to a reduction in the local permeability value. In Figures 4.3-1 and 4.3-2 are shown the air permeability of respective zones in the hydrology boreholes, measured at different stages of the test up to 9 months of heating. The permeability is plotted as a ratio with respect to their respective pre-heat November 1997 values. Only those measurements which indicate more than a reduction of 10% (precision of air injection measurements) are shown in Figures 4.3-1 for zones in boreholes 57 through 61, and in Figure 4.3-2 for zones in boreholes 74 through 78. Borehole sections where decrease in permeability were measured at different stages of heating as displayed in Figures 4.3-1 and 4.3-2 are consistent with those condensation zones predicted from the numerical model (Birkholzer and Tsang, 1998). The simulated fracture liquid saturation at 3, 6, and 9 months of heating are shown in Figures 4.3-3 and 4.3-4, in the xz cross sections containing the fan of boreholes 57 through 61, and the fan of boreholes 74 through 78 respectively. Denotation for borehole sections by borehole number follow by the zone number in Figures 4.3-1 and 4.3-2 are such that zone 1 refers to the borehole section closest to the borehole collar, and zone 4 refers to the borehole section between the fourth packer and the bottom of the borehole. In Figures 4.3-3 and 4.3-4 the locations of the packers in the boreholes are denoted by the white circles. In most boreholes the first packer closest to the collar is off-scale, the exception is borehole 58, where only 3 packers were installed and therefore 58-3 refers to the borehole section between the third packer and the bottom of the borehole. Furthermore, in borehole 77, of the three packers installed, the third packer has been damaged and deflated since March 1998, leaving essentially only one zone, 77-1 for which air permeability measurements are meaningful. Simulated results in Figure 4.3-4 show that saturation build-up in the fractures occur in zones 60-2 and 61-2 as early as 3 months after initiation of heating. As heating progress to 6 and 9 months, condensation also extends to 60-3, 60-4, 61-3, and eventually to those boreholes above the heated drift, 59-2, 59-3, 59-4, as well as in 58-1 and 58-2. Air permeability data in Figure 4.3-1 indicate that the only borehole sections which show decrease in permeability are 60-2, 3, 4; 61-2, 59-2, 3 and 58-2. The measured permeability in 58-2 and 60-4 show an initial large decrease, then subsequent rise (though not reaching their pre-heat values) as the heater test progresses. This behavior is not anticipated in the simulated results based on a homogeneous description of the fracture continuum. It can be caused by gravity drainage through fractures after an initial build up of condensation; drainage can be expected to be spatially heterogeneous, since fracture can have different orientations, and are of different length scales. Data in Figure 4.3-2 show that zones of decreased air permeability occurred in boreholes 78 and 76 for the first 9 months of heating, which is again consistent with the predicted fracture liquid saturation at 3, 6, and 9 months of heating shown in Figure 4.3-4.

Though air-injection tests in the hydrology holes were intended mainly to locate zones of increased fracture liquid saturation from condensation, post-test characterization of the Single Heater Test have indicated an overall increase in air permeability in the test block which may be attributed to microfracturing. For this reason, the air permeability data in the Drift Scale Test were also studied to unveil any thermal-mechanical coupled effects. We screened our data to investigate only those upward inclining boreholes that are farthest from the heaters, i.e. boreholes 57 and 74, where condensation was not yet anticipated at 9 months of heating. The measurements do show an increase in permeability during tests for zones 57-3, 57-4 and 74-4. These and air-injection data yet to be collected as the heating phase progress will be studied closely in order to sort out the thermal-hydrological and thermal-mechanical coupled processes.

Gas tracer tests in boreholes 74, 75 and 76 have indicated an effective fracture porosity on the order of 0.01. This values is orders of magnitude higher than what is deduced from a parallel plate conceptualization of fractures together with the ESF fracture mapping data. It was suggested that the large value of fracture

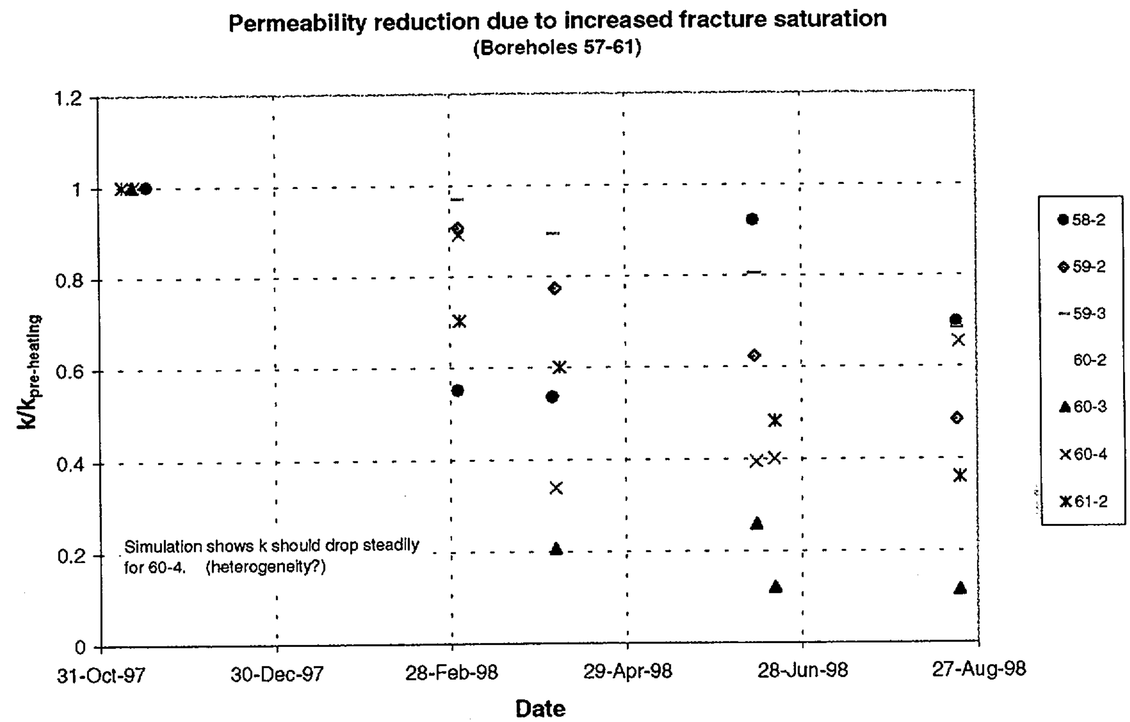


Figure 4.3-1 Decrease in measured air permeability (normalized to respective pre-heat values) due to increase liquid saturation for zones in boreholes 57 through 61.

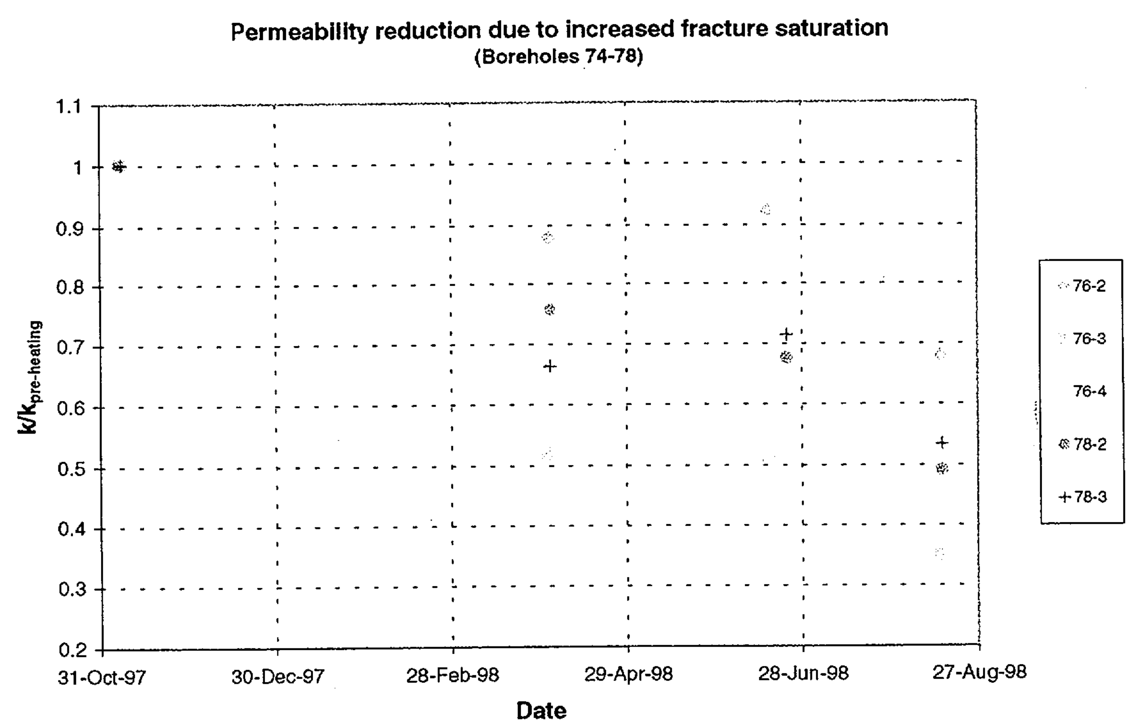


Figure 4.3-2 Decrease in measured air permeability (normalized to respective pre-heat values) due to increase liquid saturation for zones in boreholes 74 through 78. (DTN:LB981016123142.002)

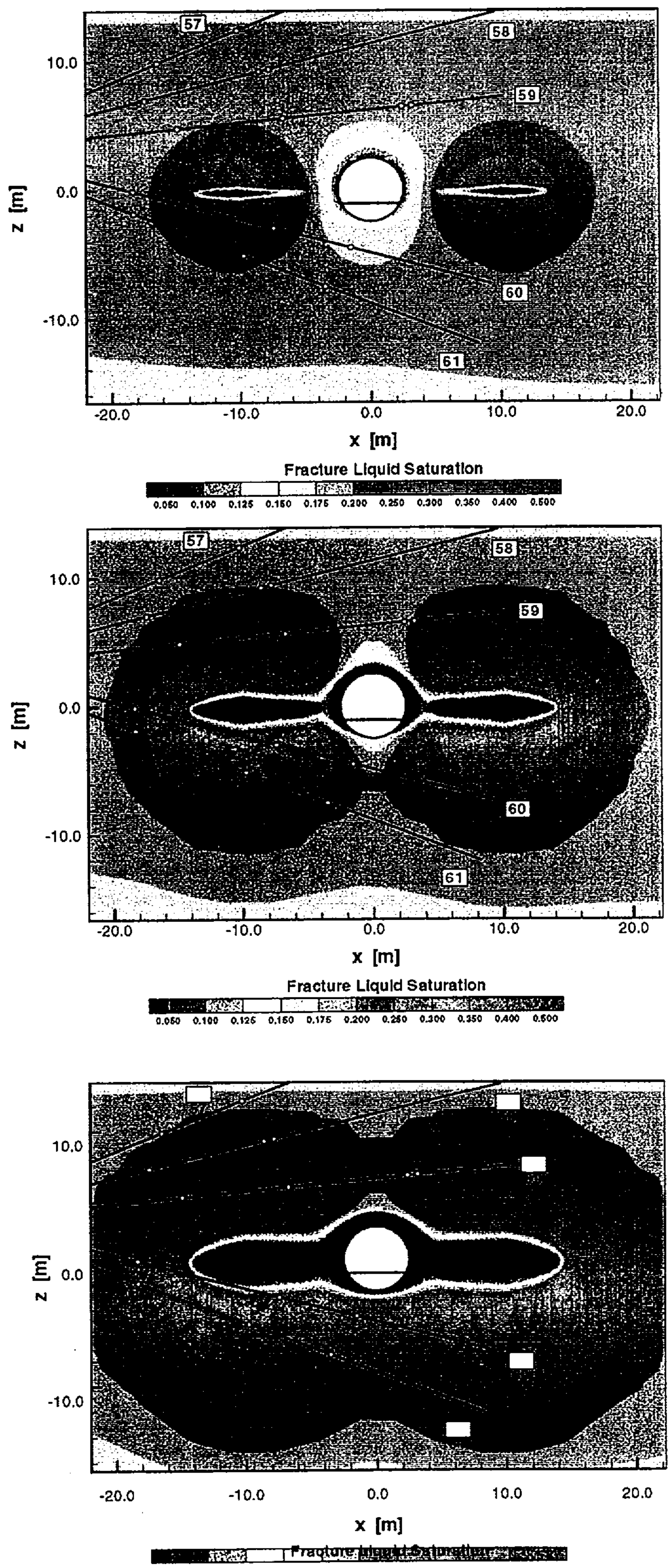


Figure 4.3-3 . Simulated fracture liquid saturation at 3 (top), 6, and 9 (bottom) months after heating in boreholes 57 through 61.

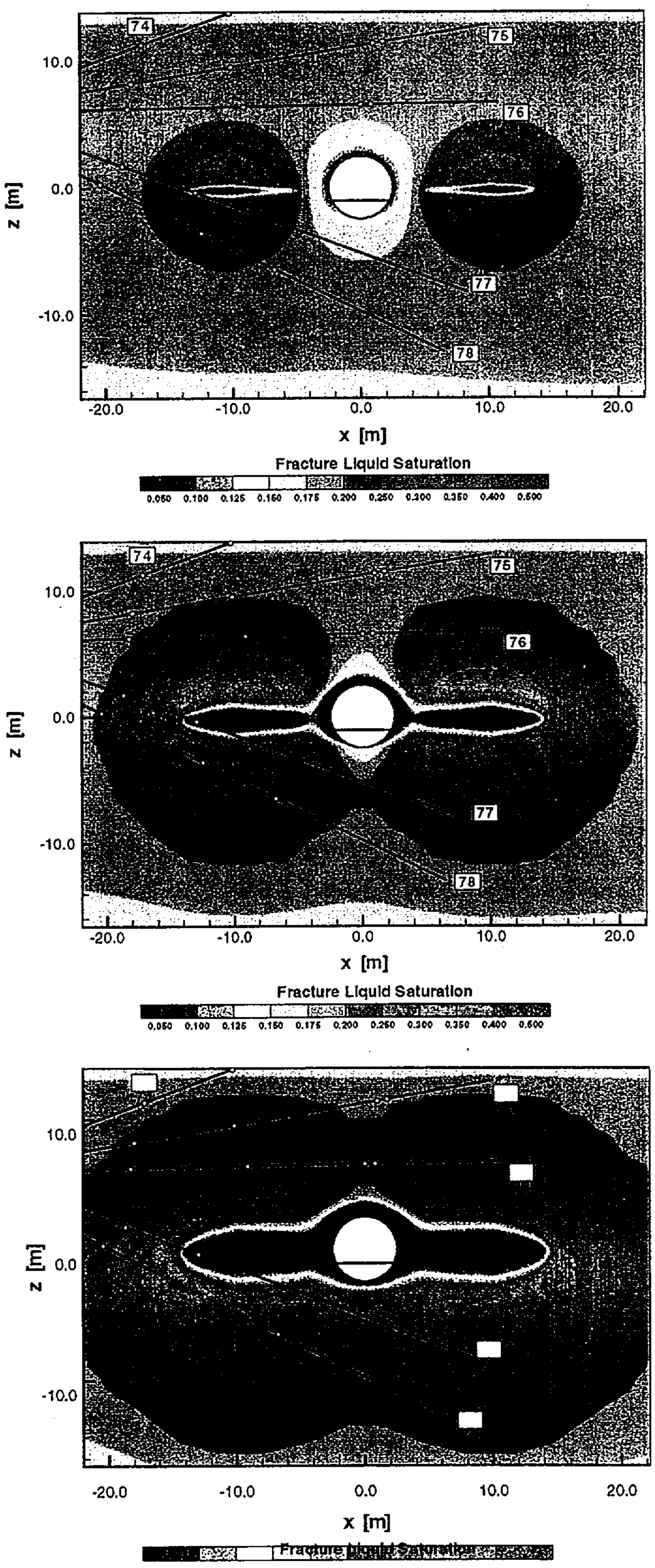


Figure 4.3-4 Simulated fracture liquid saturation at 3 (top), 6, and 9 (bottom) months of heating for boreholes 74 through 78

4.4 ERT MEASUREMENTS

Electrical Resistivity Monitoring of the Drift Scale Test: June-August, 1998
A. Ramirez, W. Daily

Introduction:

This letter report describes electrical resistance tomography (ERT) surveys made at the Drift Scale Test (DST), during the June to August, 1998 time period. ERT is one of the several thermal, mechanical, and hydrologic measurements being used to monitor the rock-mass response during the DST. The purpose of this work is to map the changes in moisture content caused by the heating of the rock mass water, with a special interest in the movement of condensate out of the system..

The purpose of this letter report is to provide a brief synopsis of the progress made during the time period of interest. A comprehensive discussion of the process followed to produce the results shown here, equipment used, and assumptions made can be found in Wagner, 1998, pages 7-13 to 7-21.

Changes in Electrical Resistivity:

Tomographs of resistivity change corresponding to the time period between June 3, 1998, and August 18, 1998, are shown in Figures 4.4-1, 4.4-2, and 4.4-3. The top part of each of these figures shows the tomographs collected along a cross-section parallel to the Heated Drift (HD). The lower left portion of the figures shows tomographs corresponding to a vertical plane intersecting the HD at right angles, and about 5 meters in from the bulkhead; we will refer to this plane as AOD 1. The lower right portion of the figures corresponds to a second vertical plane intersecting the HD at right angles, about 24 meters in from the bulkhead; we will refer to this plane as AOD 5.

The upper part of Figure 4.4-1 shows the changes in resistivity along the HD, calculated after 182 days of heating. Note that most of the tomographs are yellow-green in color, thereby indicating resistivity ratios near 1.0 (no change relative to the pre-heat case). Near the walls of the HD, the tomographs show resistivity ratios less than 1.0, thereby indicating that the resistivity has decreased relative to the pre-heating condition. After 224 days of heating(upper portion of Figure 4.4-2), most of the rock still shows a ratio of 1.0, but the rock near the crown and invert of the HD shows stronger resistivity decreases (ratios farther removed from 1.0). These decreases become stronger as heating time increases (upper portion of Figure 4.4-3). The tomographs also indicate that the resistivity changes above the HD are stronger than those below the HD. We believe that these resistivity changes are due primarily to increases in temperature that have developed close to the walls of the HD.

The lower left portions of Figures 4.4-1, 4.4-2 and 4.4-3, shows the tomographs corresponding to AOD 1. Although the mesh consists of a large region around the electrode arrays, only the region inside the ERT electrode array is shown in the figure because the region outside the array is poorly constrained by the data. The region inside the HD is also masked because the technique does not measure rock properties in the excavated region. The tomograph sequence shows a region of resistivity decrease near the walls of the HD. The resistivity decreases become stronger with time and they extend farther into the rock above the HD. Surprisingly, the region corresponding to the wing heaters location (nine o'clock position relative to the HD) shows relatively weak resistivity decreases.

The lower right portions of Figures 4.4-1, 4.4-2 and 4.4-3, depicts resistivity-change tomographs sampling the rock mass along AOD 5, which is a second vertical plane that intersects the HD at right angles near its middle. The images show both increases (ratios greater than 1.0) and decreases near the location of the wing heaters. Resistivity decreases are also observed near the walls of the HD. We suggest that the resistivity changes observed through August, 1998, are caused by temperature increases as well as saturation decreases. The AOD 5 results in Figures 4.4-1, 4.4-2 and 4.4-3 make it clear that resistivity increases are observed in the rock closest to the wing heaters while resistivity decreases are observed

Figures 4.4-4, 4.4-5, and 4.4-6. Most of these occur below the HD, near the bulkhead as well as in discrete zones closer to the middle of the HD. Another wetting zone appears above and near the edge of the wing heater location, within plane AOD 5.

All of the saturation estimates presented are considered to be approximations. The accuracy of the saturation estimates in may be limited by one or more of the factors listed in Wagner, 1998.

References:

Ramirez, A., and W. Daily (1997). *Electrical Resistivity Monitoring of the Thermomechanical Heater Test in Yucca Mountain.* Milestone report for the CRWMS Management and Operating Contractor, U.S. Department of Energy. (SP9215M4) Livermore, CA: Lawrence Livermore National Laboratory.

Wagner, R., 1998, Drift Scale Test Progress Report No. 1 (BAB000000-01717-5700-00004, Draft A), August 1998, TRW Environmental Safety Systems Inc., Las Vegas Nevada.

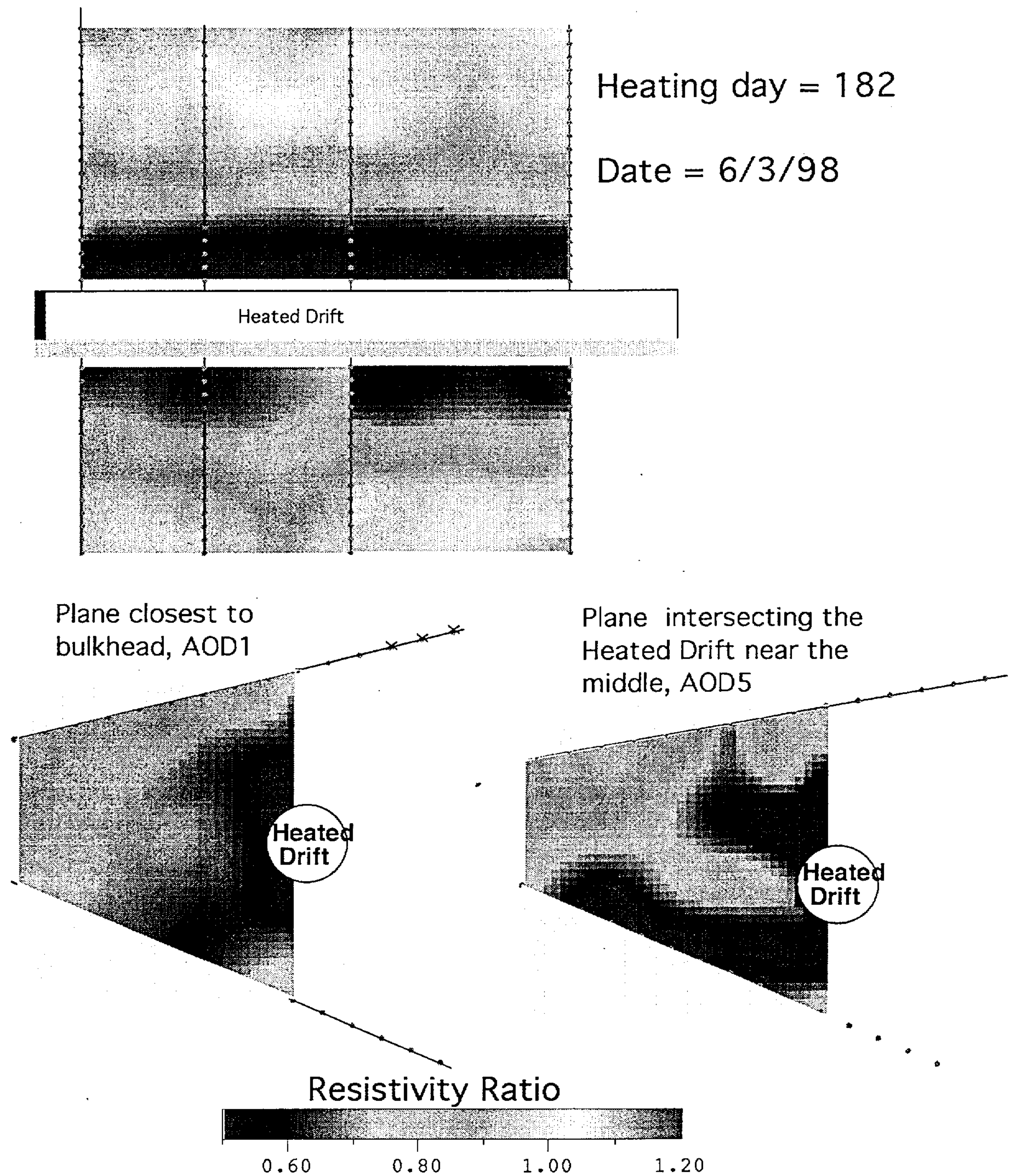


Figure 4.4-1. Tomographs of electrical resistivity ratio for heating day 182. The tomographs show changes relative to the preheating (November 18, 1997) electrical resistivity distribution. A resistivity ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the resistivity is decreasing relative to the baseline.

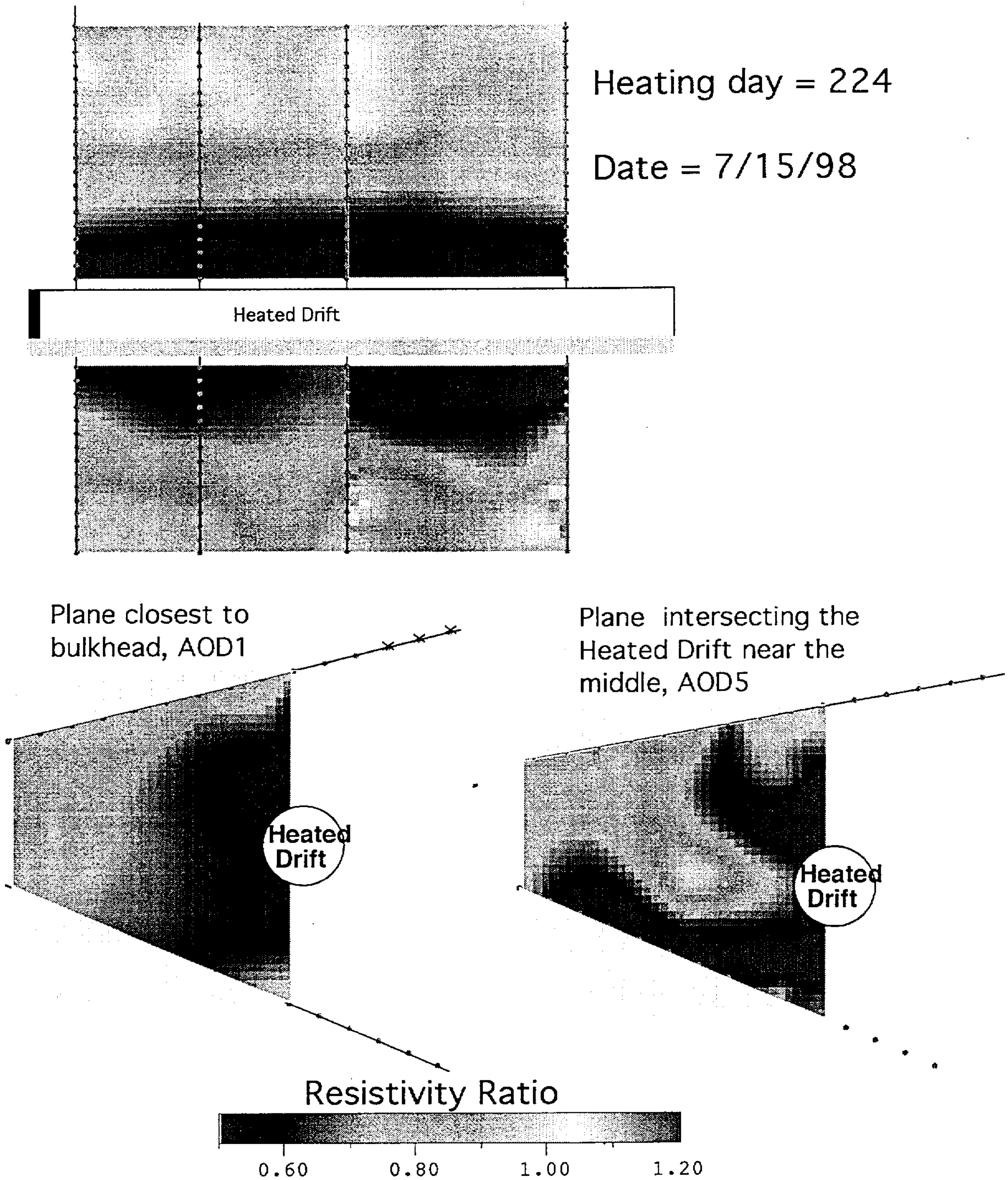


Figure 4.4-2. Tomographs of electrical resistivity ratio for heating day 224. The tomographs show changes relative to the preheating (November 18, 1997) electrical resistivity distribution. A resistivity ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the resistivity is decreasing relative to the baseline.

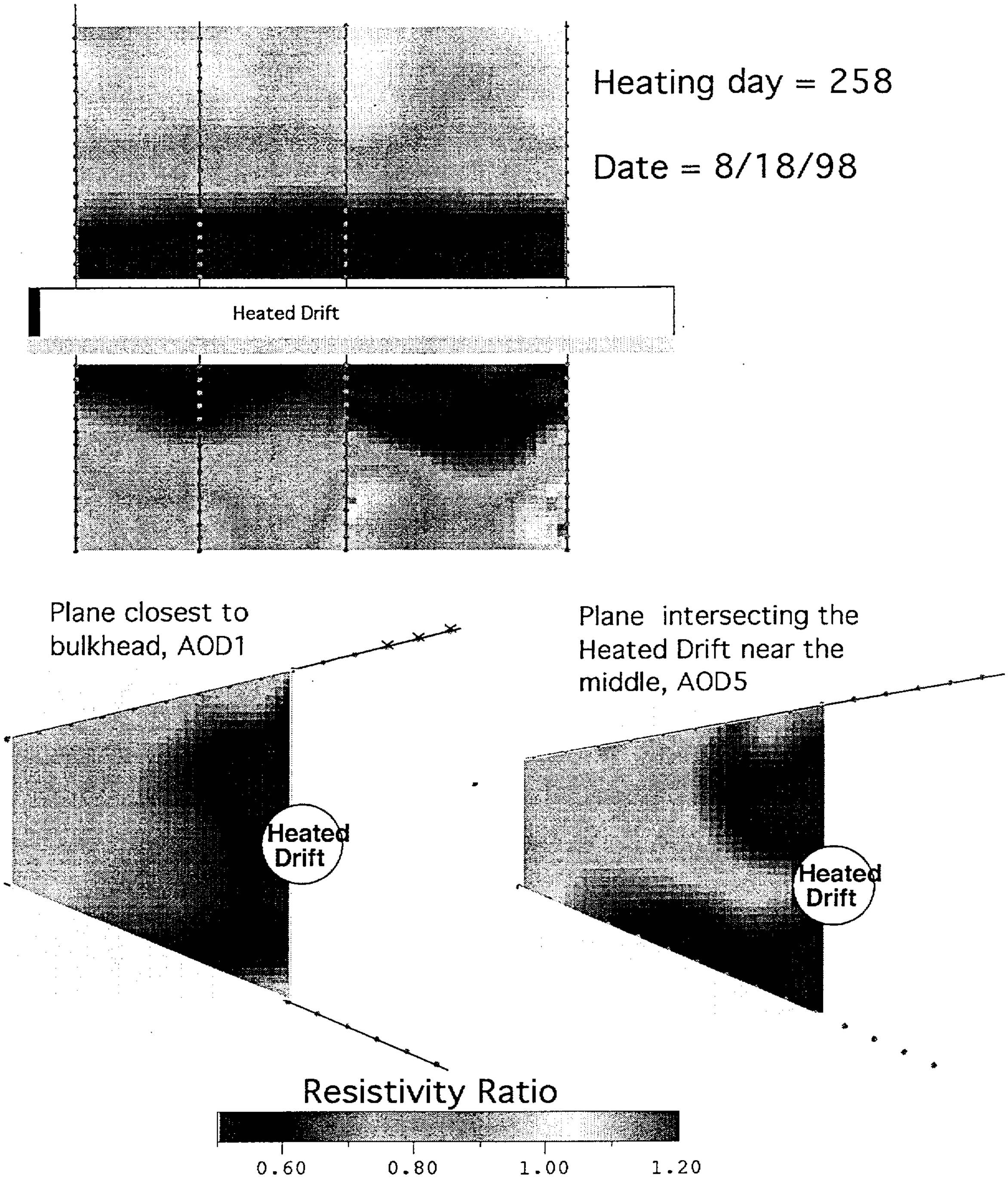


Figure 4.4-3. Tomographs of electrical resistivity ratio for heating day 258. The tomographs show changes relative to the preheating (November 18, 1997) electrical resistivity distribution. A resistivity ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the resistivity is decreasing relative to the baseline.

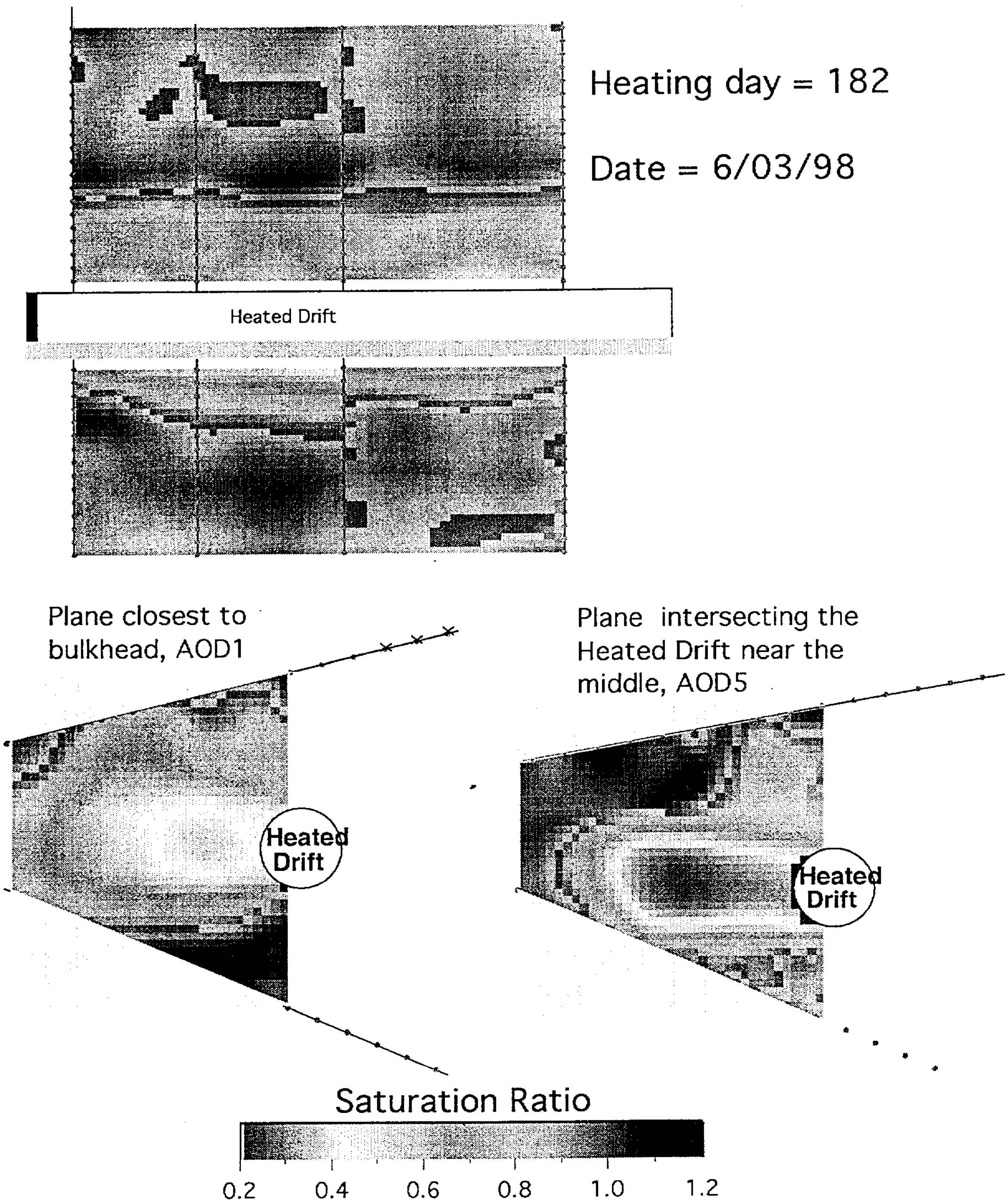


Figure 4.4-4. Tomographs of saturation ratio for heating day 182. The tomographs show changes relative to the preheating (November 18, 1997) saturation distribution. A saturation ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the saturation is decreasing relative to the baseline.

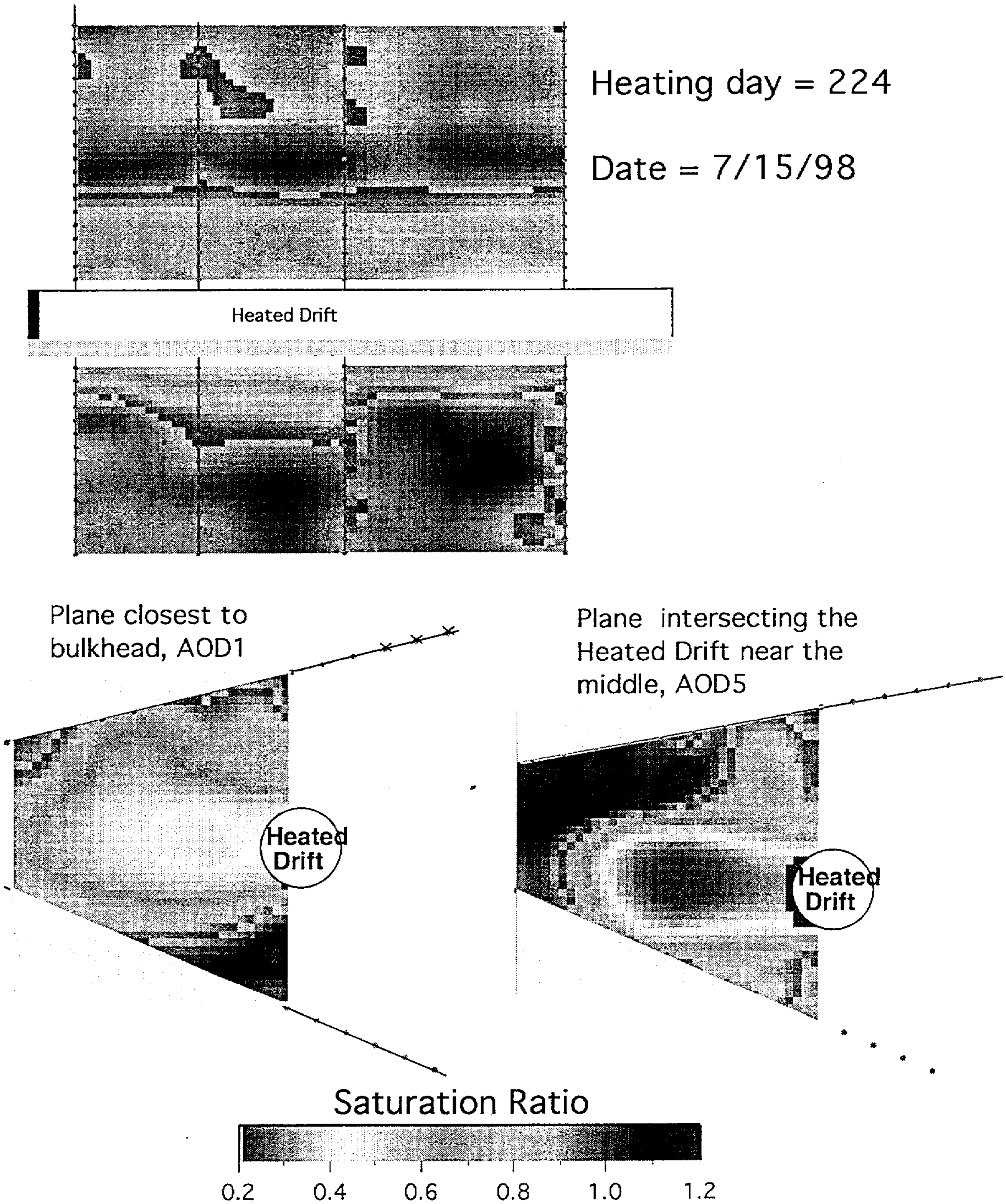


Figure 4.4-5. Tomographs of saturation ratio for heating day 224. The tomographs show changes relative the preheating (November 18, 1997) saturation distribution. A saturation ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the saturation is decreasing relative to the baseline.

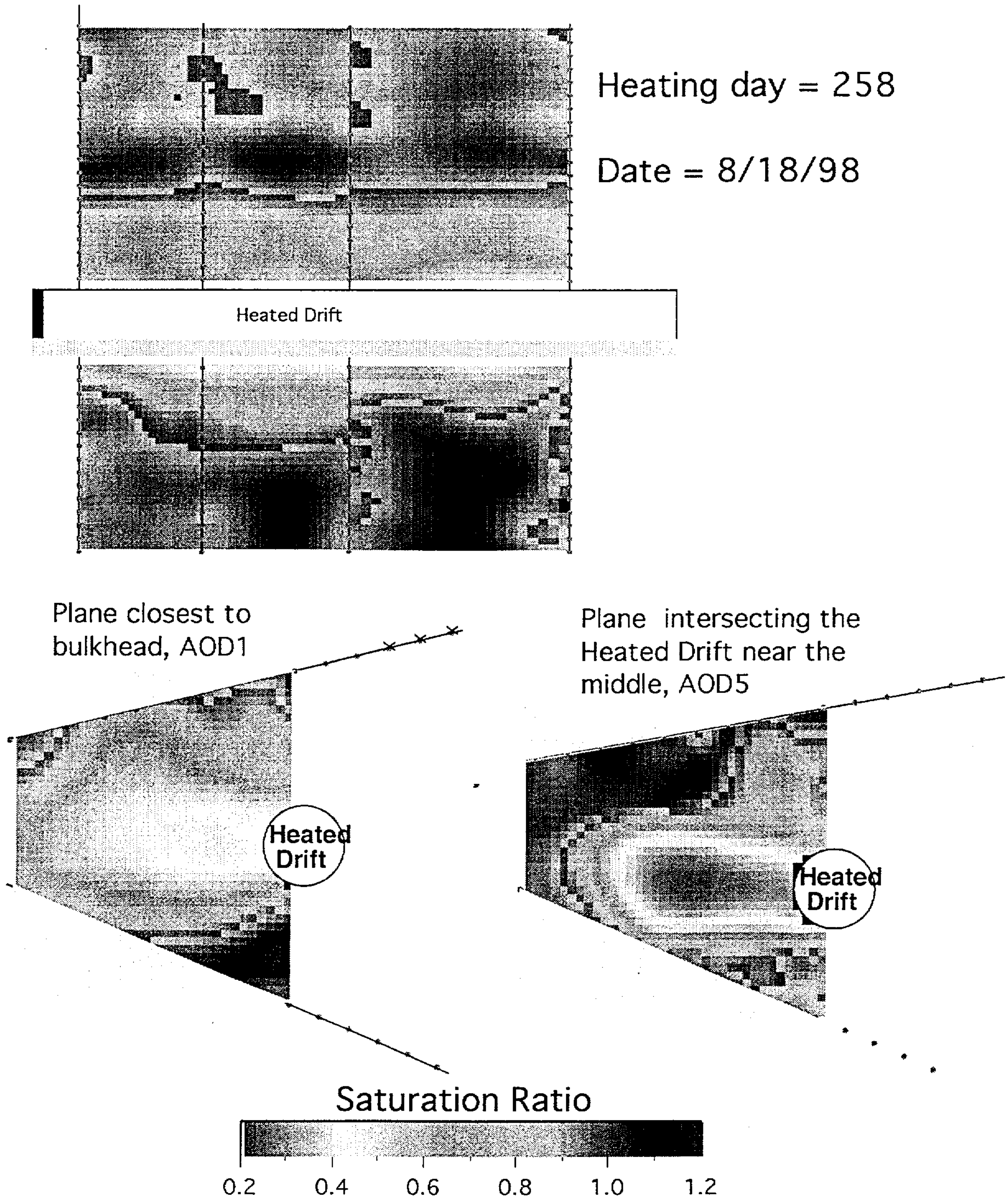


Figure 4.4-6. Tomographs of saturation ratio for heating day 258. The tomographs show changes relative to the preheating (November 18, 1997) saturation distribution. A saturation ratio equal to 1.0 indicates no change; values less than 1.0 indicate that the saturation is decreasing relative to the baseline.

4.5 GROUND PENETRATING RADAR MEASUREMENTS

Over the past several months, a variety of problems have been encountered by the ground penetrating radar(GPR) data acquisition system in support of the Drift Scale Test. The high temperatures present in several of the boreholes have resulted in equipment failures prohibiting successful and timely radar data acquisition. Specifically, it appears that the high temperatures resulting from the close proximity of the boreholes to the wing heaters directly short the radar antennas along weak points and cable connections. Much effort has been expended in determining the exact location of such weak points.

Initially, the focus of our attention was the cable head connection joining the dipole antenna to the coaxial lead-in cable. It was believed that by removing this potential failure point the system would resume normal operation – even at greatly elevated temperatures. A preliminary design was built and tested with no cable head connection. The results were extremely encouraging: the antennas were operated at the highest borehole temperatures with no loss in signal strength or transmitter amplitude over periods of time longer than those expected during normal data acquisition. It should also be noted that although the coaxial cable was not rated for the expected temperature (140ЂC), it performed acceptably and within the standards specified by the manufacturer. Additionally, a small scale GPR survey was undertaken using the prototype system in four of the hottest boreholes (Borehole Numbers 50-51 and 67-68). Because of problems with cable availability, the cables were shorter than the length necessary for a complete survey. As such, the survey was conducted from roughly 23.0 to 18.0 meters down the boreholes. Fortunately, this region is associated with the highest borehole temperatures and the greatest degree of formation drying. Results appear encouraging from a data quality standpoint but final data analysis and interpretation is still underway.

Based on these results, a final design was settled upon and the modified antenna system was fabricated. Unfortunately, cable availability again became a problem and a decision was made to utilize existing coaxial cable for the modified design. The available cable was that coaxial cable previously used at the Drift Scale Test. It was believed that the weak points in this cable were confined to the region nearest the cable head connection. A portion (1-2 meters) of the existing coaxial cable was removed and the dipole antenna directly connected to the shortened cable resulting in a design that would perform similarly to the prototype design and be of a length suitable for the Drift Scale Test survey (35 meters). Subsequent testing proved that our assumptions were partially incorrect. The new antenna design again failed to function properly when subjected to the elevated borehole temperatures. It became clear, however, that temperature was not the only factor in causing antenna failure. Cable stress also appeared to play a role. The first two radar surveys completed at the Drift Scale Test were accomplished by using aluminum push rods to forcibly locate the radar antennas to a desired depth. Especially in the steeply inclined boreholes, the emplacement of the antennas likely caused damage to the coaxial cable at those points where the push rods were strapped to the cable. This location varied depending on the inclination of the borehole and the depth of the survey, and as a result, multiple locations have probably been affected. Thus, when these damaged cable locations were placed under stress and elevated temperatures, electrical shorting and antenna failure was the result (i.e. low or no signal strength).

The failure of the existing cable has forced the procurement and assembly of a new system. The design of the system is to be identical to the one specified above with one notable exception. The new cable will be composed of coaxial cable rated to high-temperature (200+ЂC) covered in a rugged, abrasion-resistant coating also rated for high-temperature (200+ЂC). Additionally, as part of an effort designed to develop a less damaging method for emplacing the radar antennas in the boreholes, a locking pulley system was conceived and built. This device now allows us to lock (and later remove) a pulley at 40 meters depth down a borehole. Using this pulley and an attached high-temperature string, we are able to gently and efficiently pull an antenna to a desired depth. This has proven to be extremely successful and will be very valuable in reducing cable damage in the future. It is now believed that by utilizing the undamaged, high-temperature coaxial cable along with the locking pulley system, the means exists to successfully resume GPR data acquisition in support of the Drift Scale Test.

4.6 Neutron Logging Measurements

There are twelve holes in the Drift Scale Test for measuring the moisture content of the rock by neutron logging.. Ten of these holes in two fans transversely orthogonal to the Heated Drift are from the observation drift. The other two holes are drilled from the connecting drift, parallel to the Heated Drift (HD) at approximately 1m above its crown and approximately 9.5m from the centerline of the HD on either side of it.

A teflon tube is grouted in the neutron holes to facilitate movement of the probe. Since the grout contains moisture, the neutron logging system needs to be calibrated in simulated rock of known moisture content and hole and teflon tube of same diameter and same grout conditions. The neutron count from the logging is processed using the calibration data to yield moisture content of the rock. Although logging in the DST are being performed regularly since before the start of heating, calibration of the tool is not complete. For this reason, true moisture content of the logged intervals in the DST is not yet available. All actual test runs associated with the calibration of the DST neutron tool have been completed and the data is being processed at this time. Data on the true moisture content of the rock will be available in the near future.

Notwithstanding the above, preliminary qualitative conclusions regarding the drying of the rock can be made by analyzing the neutron count obtained by logging. Such analyses indicate that the rock surrounding some sections of neutron holes # 4 , 9 and 12 has been drying. Both neutron holes #4 and 9 are down holes and the drying sections not far from the outer segment of a nearby wing heater. Neutron hole #12 is parallel to the HD and the drying section in this hole is also due to wing heaters below it.

4.7 GAS SAMPLING AND ANALYSIS

Introduction

CO_2 concentrations in the rock around the Heater Drift have increased significantly since the initiation of heating. Numerical models of the system indicate that the source of this CO_2 is exsolution of dissolved inorganic carbon compounds (DIC) such as $CO_3^{=}$, HCO_3^{-} and dissolved CO_2 from the pore waters in the rock during heating. With ~90% of the pore space in the rock filled with water, the capacity of the water to hold carbon in the form of DIC is much greater than the capacity of gas phase to hold CO_2 (on the order of 100 times as much, depending primarily on the pH and temperature). As the temperature rises, the partitioning of inorganic carbon between the gas and liquid phases shifts, with a higher proportion going into the gas phase. When the rock reaches the boiling point of water, the CO_2 concentrations will increase even more quickly until the rock dries out and all the inorganic carbon goes into the gas phase. The changing DIC concentrations in the pore fluids will have a significant impact on the chemistry of the pore fluids (especially on pH), which could strongly affect which mineral phases will be dissolved or precipitated.

The stable carbon isotopic ratios ($ə^{13}C$ values) of CO_2 from around the heater drift have been measured in order to confirm the source of the increased CO_2 and to constrain parameters such as the changing pH of the pore waters and the nature of gas transport in the heated rock. This is possible because CO_2 and DIC in carbon isotopic equilibrium will have different $ə^{13}C$ values depending primarily on the temperature and pH of the fluids. As a result, the $ə^{13}C$ values measured for CO_2 will change as a higher proportion of the DIC in the pore waters is converted to CO_2. The way in which the $ə^{13}C$ values of the CO_2 vary with time and temperature around the heater drift can then be used to place limits on pH and gas transport in the system.

Data

The $ə^{13}C$ values of the potential sources of CO_2 in the tunnel were measured. This data is presented in Table 4.7-1. It is significant that the concentrations and $ə^{13}C$ value CO_2 from the AO Drift and the Heater Drift are similar. This indicates that the Heater Drift is essentially in equilibrium with the air in the tunnel and that the bulkhead separating the Heater Drift from the tunnel is not limiting gas exchange. It should also be noted that the $ə^{13}C$ value of CO_2 measured for rock air is close to the $ə^{13}C$ value of CO_2 that would be produced from dissolution of calcite with the $ə^{13}C$ value measured for the calcite from the AO Drift. This suggests that the $ə^{13}C$ value of CO_2 in the vicinity of the heater drift may have been fairly constant over time.

The $ə^{13}C$ values of CO_2 in gas samples collected from the hydrology holes vary depending on both the concentration and temperature of the rock. Figure 4.7-1 is a cross section of the Heater Drift that contains hydrology holes 74-78. The $ə^{13}C$ values of CO_2 from gas samples collected during August of 1998 are plotted on this figure along with the temperatures and CO_2 concentrations. The $ə^{13}C$ values are highest in samples from nearest the Heater Drift and drop off significantly in samples from further away. Similar patterns were seen in gas samples from the other intervals that were sampled. The variations in the $ə^{13}C$ values do not directly correlate with either the temperature measured for the interval sampled or the concentration of CO_2. This is believed to be primarily caused by the large sampling intervals that cross areas with large temperature ranges.

The $ə^{13}C$ values of the CO_2 also varied with time. Figure 4.7-2 contains data collected from two of the intervals in the hydrology holes that were sampled over the last 8 months. Interval 77-3 is from the hottest part of the system. By February, the temperature was already greater than 80°C. The CO_2 concentrations were also high and increased to greater than 33,000 ppm (3.3%) by August. By October, the temperatures in this interval had increased past the boiling point of water and the CO_2 concentration had dropped down to 2160 ppm, presumably because the pore waters in the area had boiled away (although, given the large size of this interval, it is unlikely that the whole region had dried out). The carbon isotope data is consistent with this interpretation. In February, the $\delta^{13}C$ value of the CO_2 was already much higher than the background, indicating a significant input of CO_2 from pore water DIC. As the CO_2 concentrations increased, so did the $\delta^{13}C$ values of the CO_2. When the region began to dry out, the $\delta^{13}C$ value of the CO_2 decreased slightly (representing CO_2 coming from cooler areas of the system?).

Conversely, interval 57-3 is from a hole that extends above the Heater Drift at ~10 m from the bulkhead. By early October, when the last sample was taken, the temperature of the interval was only 25.5°C. However, the CO_2 concentrations had increased to approximately twice the initial concentration and the $\delta^{13}C$ values of the CO_2 had dropped down to -16‰. This indicates that CO_2 evolved from pore waters in the hotter areas of the system closer to the Heater Drift is expanding out into the rock, causing CO_2 concentrations in the cooler areas of the system to increase despite no significant increase in temperature. The $\delta^{13}C$ values of the CO_2 in the cooler areas are decreasing because a significant amount of the CO_2 is being absorbed into the pore waters as DIC. The CO_2 dissolving into the pore waters will have higher $\delta^{13}C$ values causing the remaining CO_2 to shift to lower $\delta^{13}C$ values.

Implications

The carbon isotopic data for the CO_2 suggest a couple of initial conclusions. First, the increased concentrations of CO_2 in the rock around the Heater Drift are probably derived from DIC in the pore waters. It is also possible that some of the CO_2 could be from dissolution of calcite in the rock. The second finding is that gas transport around the Heater Drift is relatively fast. In order for the $\delta^{13}C$ values of the CO_2 to increase as much as they have (from -13‰ to greater than -3‰), the system must be open. In a closed system, the $\delta^{13}C$ values of the CO_2 could not increase above the initial $\delta^{13}C$ value of the DIC in the pore waters (approximately -6‰). To rise to greater than -6‰ requires that the initial, lower $\delta^{13}C$ CO_2 that is evolved from pore water DIC be flushed out of the system. Simple calculations suggest that the residence time of CO_2 in the rock is relatively short (complete turn-over every few days). The only reason such high concentrations of CO_2 are maintained in the rock is because of the much higher starting concentration of inorganic carbon in the pore waters.

Reference

Wigley, T.M.L.; Plummer, L.N.; and Pearson, F.J. 1978. "Mass transfer and carbon isotope evolution in natural water systems." *Geochim. et Cosmochim. Acta 42*, 1117-1139.

Table 4.7-1. Average concentrations and ə^{13}C values of CO_2 from the area of the heater drift.

	# of Measurements	ppm CO_2	ə$^{13}C_{VPDB}$ (‰)
1. AO Drift Air	4	430	-10
2. Heater Drift Air	2	420	-10
3. Rock Air[1]	1	900	-13
4. Calcite[2]	2		-6

[1] Sample of gas collected from borehole 182 in the

[2] Data for calcite samples taken from fractures in the AO Drift. The ə^{13}C value given is the measured value for calcite. This is different than the ə^{13}C value of CO_2 that would be produced from dissolution of the calcite depending on the temperature and the pH of the fluids. At 20°C and a pH of 7, the equilibrium ə^{13}C value for CO_2 will be approximately -14‰ (Wigley et al., 1978).

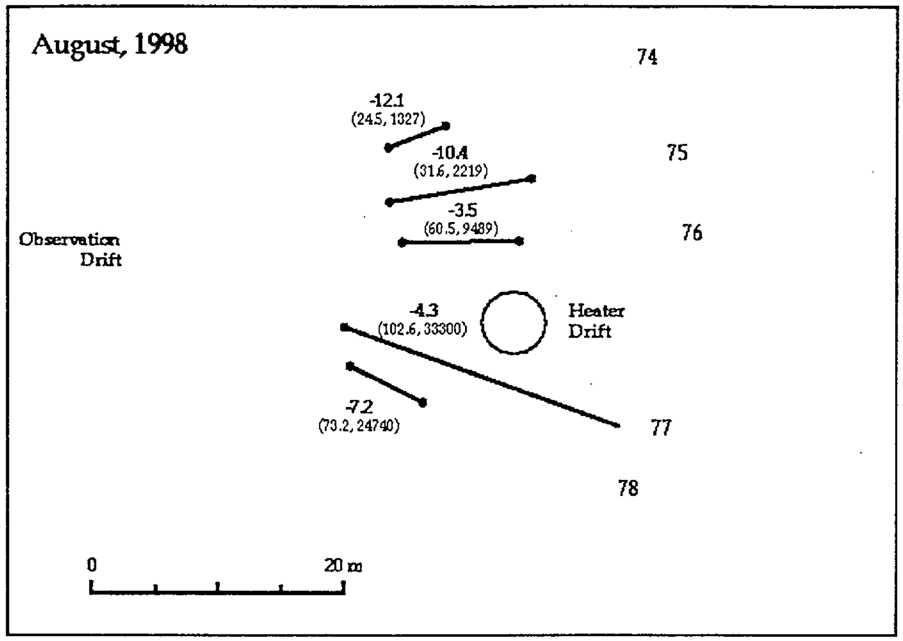


Figure 4.7-1. ə^{13}C data for CO_2 (in ‰ units relative to VPDB) in gas samples collected during August of 1998 from Hydrology boreholes around the Heater Drift. Also shown are the temperatures (°C) and concentrations of CO_2 (ppmv).

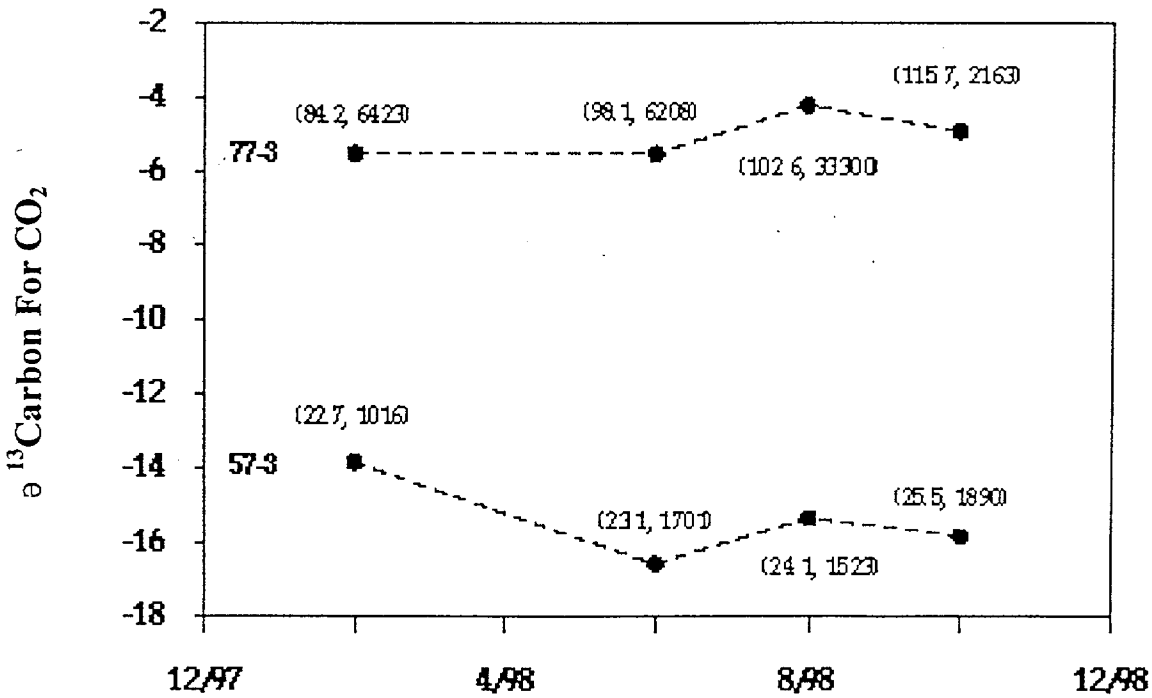


Figure 4.7-2. Plot of ə^{13}C data for CO_2 (in ‰ units relative to VPDB) in gas samples collected from intervals 77-3 and 57-3 in the LBNL Hydrology boreholes. Also shown are the temperatures (°C) and concentrations of CO_2 (ppmv).

4.8 ANALYSIS OF WATER SAMNPLES

The major cation and anion chemistry of the waters recently sampled from the Drift Scale Test has been analyzed. Several water samples were obtained from the hydrology holes, and pads contacting wet borehole walls were collected from the liners installed in the chemistry boreholes. An aqueous sample was also collected from one of the chemistry boreholes during gas sampling.

The samples were all analyzed with respect to the cations Si, Na, Ca, Mg, Sr, Al, K, Fe, S, B, and Li by the method of Inductively-Coupled Plasma and Atomic Emission Spectrometry (ICP/AES). The anion analyses performed by Ion Chromatography (IC) included F, Cl, Br, NO_2, NO_3, PO_4, and SO_4. A field measurement was also made of pH and temperature in most instances at the time of collection.

Water Samples Collected From The Drift Scale Test

Aqueous samples have been collected from the hydrology boreholes where packed-off intervals separate zones open to the borehole walls. To date, water has been sampled from two of these hydrology boreholes: borehole 60 and borehole 77 occupy corresponding positions in two different borehole arrays. Both boreholes are collared in the observation drift, run normal to the heater drift plane, and angle downward and below the heaters. The first water from the hydrology boreholes was taken 6 months after heater turn-on, in two zones of borehole 60. Samples were collected again from these zones and from borehole 77 about 2 months later.

Water samples taken for chemical analysis from the chemistry boreholes were first collected in April of 1998 (~4 months after the start of heating). At that time the first absorber liner was removed from borehole 55, and the attached absorber pads were collected for analyses. This borehole corresponds in orientation and position within its borehole array to the two hydrology holes from which the previously described water samples were taken. The absorbent pads installed on the liner were positioned every 4m along the length and all appeared to be saturated. One pad, however, located ~18m into the hole was beginning to show signs of drying. Another liner was pulled in June, and again all the pads appeared to be wet. The second liner was pulled from borehole 56, the borehole immediately below 55. In the case of liner 56, the pads visually did not appear to be as wet as for those collected from 55.

Liquid water was also collected on one occasion from the chemistry boreholes. During gas sampling, an in-line water trap collected ~ 30 mls of water as air was pumped from the gas sampling ports to the analysis unit. This water came from borehole 54, within the same array of chemistry holes as 55 and 56, but which is angled upward and immediately above the heaters in the drift. The sampling port which yielded water was located almost at the end of the borehole, at a distance of ~35m in from the collar. This water was collected for sampling and analysis, but it was unexpected, and a formal sampling protocol had not been established.

Sample Handling and Processing

The borehole water samples from the hydrology holes were collected and filtered through a 0.45 €m pore filter. These water samples were stored in polyethylene containers and were either immediately stabilized with HNO_3 for sample splits designated for cations, or the containers simply went into refrigerated storage until they could be sent for analyses. The controlled thermal conditions were unable to be maintained throughout the entire shipping and transfer process, however.

The sample collection of absorber pads included the immediate removal from the retrieved borehole liner and storage in clean, air-tight polyethylene bags. A visual examination showed that the pads suffered from gross contamination of rock and soil particulates that could not easily be excluded during processing in the lab and therefore introduced significant uncertainty into the analytical results. Another potential contaminant was the pervasive presence of mildew on the pads.

Analytical Chemistry Results

The measured cation and anion chemistry of the aqueous samples are reported in Table 4.8-1. Hydrology hole samples are identified by the borehole number and the zone. The chemistry hole sample is identified by the borehole number and the gas sampling port number. In addition to this identification descriptor, all samples have also been given a YMP bar code for sample tracking which is reported as the SMF number. The table includes the sample collection date and field measured values of pH, temperature, and Br concentration if available. All the samples have a Q-pedigree, except for the chemistry borehole water, 54-1. All the analytical data are qualified.

The pad data that have been collected to date are not reported. As previously mentioned, the pads were recognized to be contaminated, and although efforts were made to reduce the contamination from areas analyzed, results are suspect. Additional analyses were also performed to understand the contribution to background levels that the pad generates. These analyses revealed significant heterogeneity of several of the analytes, further complicating the interpretation of potential geochemical changes with respect to depth or distance from heaters. Further examination of the results will determine if some of the data can be utilized.

Discussion

Several liters of water were collected from the hydrology hole #60. The water chemistry in both zones 2 and 3 is inconsistent with a simple condensate which has no history of rock/water interaction. On the other hand, the chemistry of water collected from borehole 77-3 was different; it was dilute by comparison. The temperature readings recorded for 77-3 was 102.8 ‡C which was generally hotter than the other zones from which water was collected. This borehole yielded only about 200 mls of water, and one possibility is that the sample is simply water vapor stripped from the gas as the hot air is pumped into the cooler atmosphere of the observation drift. At any rate, it is not comparable to the chemistry of the other waters sampled. Finally, borehole 54 port 1 yielded water which also does not appear to be simple condensate. Because its chemistry is suspect, however, since the process of filtration and flushing of the lines were not employed, the results should not be used to make geochemical interpretations. Instead, it may be useful to understand moisture distribution within the test, and to plan for the possibility of future water collections via the same process.

Table 4.8-1. Thermal test water chemistry.

SMF number	Suite 1 SPC00527969	Suite 1 SPC00527977	Suite 2 SPC00527915	Suite 2 SPC00527916	Suite 2 SPC00527917	H2O trap SPC00530268
collection date	06/04/1998	06/04/1998	08/12/1998	08/12/1998	08/12/1998	06/04/1998
temp (C)	36.2	82.1	60.2*	91.6*	102.8*	
field pH	7.5	7.7	6.9	6.8	5.5	7.32
field Br (ppm)*	0.75	0.96	0.385	0.345	0.392	
Na (mg/l)	20.0	24.0	20.4	17	2.4	27.0
Si (mg/l)	56	41	51.8	44	1.48	509
Ca (mg/l)	20	25	19.9	19	2.09	28.8
K (mg/l)	6.0	4.5	5.4	4.5	1.4	n.d. < 0.5
Mg (mg/l)	2.9	5.7	1.21	4.0	0.21	5.79
Al (mg/l)	0.12	n.d.< 0.06	n.d.<0.06	n.d.<0.06	n.d.<0.06	n.d. < 0.06
B (mg/l)	1.2	0.92	1.84	1.1	0.13	1.71
S (mg/l)	5.5	9.2	4.5	5.2	1.4	16.6
Fe (mg/l)	0.04	n.d. < 0.02	0.02	0.12	n.d. < 0.02	n.d. < 0.02
Li (mg/l)	0.07	0.07	0.03	0.04	n.d. < 0.01	0.07
Sr (mg/l)	0.18	0.34	0.11	2.2	0.05	0.4
F (mg/l)	1.00	0.82	0.71	0.43	nd < .007	1.00
Cl (mg/l)	10	16	6.14	5.52	2.15	31.0
Br (mg/l)	0.84	0.73	0.05	0.21	nd < 0.03	n.d. < 0.02
SO4 (mg/l)	17	30	4.88	8.81	1.86	45.0
PO4 (mg/l)	n.d. < 0.07	n.d. < 0.07	0.25	0.16	1.06	n.d. < 0.07
NO2 (mg/l)	n.d. < 0.01	n.d. < 0.01	nd < 0.04	nd < 0.04	nd < 0.04	n.d. < 0.01
NO3 (mg/l)	3.00	3.6	0.46	0.6	0.22	9.00

* These temperatures were downloaded from the data collection system, and are not a measured fluid temperature at the time of collection.

The water sample from borehole 54-1 is not "q" and the analyses likely reflect contaminated sample

4.9 Acoustic Emission / Microseismic

Sixteen accelerometers are installed at various locations in the Drift Scale Test block to monitor micro-seismic or acoustic emissions (AE). Micro-cracking due to heating is thought to be caused by acoustic emissions. Shear movement and rock fracturing are also expected to release micro-seismic emissions. Travel time data to multiple accelerometers can be processed to locate a particular event in space. This information may then be correlated with some of the other measurements such as rock displacement. This information may be useful in understanding the process(es) taking place in the rock.

Three of the sixteen accelerometers are malfunctioning. The remaining thirteen are still adequate for isolating and locating an event. The system is subject to severe interference due to noise from any of the many other electrical systems in the DST.

After the heating started, the AE system in the DST was experiencing both severe noise interference and actual events making it difficult to isolate and locate any event in time and space. One event, considered to have been isolated , took place on January 7, 1998. The processing of the data to locate it is expected to be completed in the near future.

Recent installation of a filter to eliminate high frequency noise and a trigger selection box which will not trigger the system if emmissions reaches multiple accelerometers exactly at the same time is expected to greatly help in isolating events.

4.10 Video Imaging Inside the Heated Drift

The Camera System in the Drift Scale Test is intended to periodically take both video and infrared images inside the Heated Drift. Baseline images were collected before the start of heating in December 1997. The infrared (IR) images after the start of heating did not allow any distinctive features to be identified. This is thought to be due to extremely low temperature gradient on the surfaces being imaged. IR imaging may be useful during the cooling phase to identify any moisture vapor escaping into the Heated Drift from fractures, if there is any such event and the temperature difference between the moisture and rock surfaces in the vicinity is finite and distinguishable by IR imaging.

Video images of the inside of the Heated Drift have been collected in March, July and November of 1998. No changes of any significance has so far been noted.

4.11 Moisture Movement Across the Bulkhead

The Heated Drift is separated from the rest of the thermal testing facility by a bulkhead. The bulkhead is a thermal bulkhead, not a pressure bulkhead. It is made of a steel frame and steel plates and carries the lighting fixtures, viewing windows and the camera door. The bulkhead is insulated on both sides by fiber glass insulation pads.

The ralative humidity (RH) inside the Heated Drift dropped to approximately 15 percent during the first 10 days of heating. Thereafter, the RH inside the HD fluctuated between 10 and 25 percent with a peak to peak interval of approximately 4 days. Measured RH in the HD has been inversely tracking the air pressure in the drift. After some forty days of heating, moisture started to flow out of the Heated Drift as evidenced by condensation on various surfaces near the bulkhead and the formation of a puddle on the floor. Such wet conditions near the bulkhead alternated with dry conditions with the latter coinciding with low RH inside the HD.

The Drift Scale Test System, comprised of the HD and the surrounding heated and unheated rock, is not a closed system. The DST block is exchanging moisture and air with its surroundings through the bulkhead and the fractured rock. Outflows coincide with higher RH in the HD and lower barometric pressure.

As the rock immediately surrounding the drift is heated to above the boiling temperature, the pore water in the rock is mobilized and driven outward creating a dry-out zone around the drift. As the mobilized water in the vapor phase moves outward, it condenses when it reaches cooler regions and vaporizes again, as additional thermal pulse reaches it. A boiling zone is thus formed around the dry-out zone. Phase changes occur continuously in the boiling zone causing pressure to build up. When the barometric pressure and the pressure inside the HD are high, steam and water is confined to the boiling zone. When the barometric pressure and the pressure in the HD drop, steam and water escape from the boiling zone moving into the HD via the fractures and causing the RH in the drift to rise, much like what happens in pressure cooker or geyser.

Ways of measuring the heat loss through the bulkhead, both by conduction and convection, have been investigated. A pair of sensitive heat flux meters has been acquired and will be used to measure the heat loss by conduction in the first part of January 1999.

Measuring the loss by convection is difficult and complicated because flow takes place at numerous locations, at various rates and at different temperatures. A system employing mass flowmeters and mass spectrometers is being investigated.

4.12 THERMAL-HYDROLOGIC ANALYSIS

An interpretive analysis of the thermo-hydrological processes of the Drift Scale Test (DST) at Yucca Mountain was conducted by studying measured temperature data collected in the first 9 months of heating and comparing them with simulated results from the 3-D DST numerical model. In this model, fractures and matrix are each represented as a continuum for flow of liquid, gas and heat. The effective continuum approach (ECM) is applied in three-dimensional simulation runs, while the dual permeability formulation is used for certain two-dimensional runs to study model sensitivity to the fracture-matrix interaction concept. The numerical simulation is exercised for two different infiltration rates—the best estimate of 3.6 mm/yr for the location of the heater, and one-tenth of the expected estimate, 0.36 mm/yr—in order to include a full range of plausible responses. Infiltration is assumed to be constant in time; no episodic events are considered. Model properties are estimated from site-specific measurements whenever possible, otherwise adopted from UZ site-scale model results. Two alternative data sets are used for the DST, one associated with 3.6 mm/yr percolation, the other associated with 0.36 mm/yr percolation. The computational grid designed for the DST honors the designed test conditions as closely as possible, using a total number of 48,249 gridblocks and 157,474 connections between them (Figure 4.12-1).

The model used for the DST simulations is based on the three-dimensional predictive model developed by LBNL in 1997 (Birkholzer and Tsang, 1997). The predictive simulations were carefully reevaluated based on the first 9 months of data, and, as a result, several model refinements have been made. In general, such model refinements can be categorized as follows:

- Modification of test conditions and geometry
- Modification of model conceptualization
- Modification of model rock properties

So far, we have focused on the first two items, i.e., a better representation of the actual test conditions, and a review of the conceptual model. The following model improvements were made:

- Heater power and schedule were adjusted to 77% of maximum power for the canister heaters and 94% of maximum power for the wing heaters, representing the average measured heater power in the DST for the first 4 months of heating
- The concrete invert in the Heated Drift, originally not represented by the model, was added to the computational grid.
- The bulkhead boundary condition was modified to allow for gas transport between the hot and the cold side of the heated drift.
- The initial temperature and moisture conditions close to the Heated Drift were adjusted to account for the impact of elevated drift temperature and drift ventilation prior to heating.

Our observation so far is that the simulation results for the first 9 months of heating compare favorably with temperature data as well as with results from active hydrological testing. The model refinements all contribute to a better match between simulation results and field data, in particular the introduction of the gas-permeable bulkhead boundary condition. Our results also indicate that thermal radiation is quite effective within the Heated Drift, and can be approximated in the model by assuming totally effective black body heat radiation. Simulation runs performed for a heating period of several years show that the current heater power can probably be maintained for about 24 months of heating before the wall temperature in the Heated Drift reaches 200°C (Figure 4.12-2).

So far, no model calibration has been performed. Sensitivity studies, however, indicate that the temperature match between measured and simulated results may be further improved by using adjusted rock property sets. Hence in future modeling efforts, the model properties for the DST will have to be carefully evaluated. Sensitivity studies have also been conducted to study the impact of model conceptualization, i.e., the validity of ECM or DKM approaches, respectively. The simulated temperatures are almost identical for the two model concepts; however, obvious differences between ECM and DKM are obtained for saturation results, as the DKM method promotes gravity-driven liquid flux in the fractures (Figure 4.12-3). We may conclude from this analysis that temperature data will probably not diagnostically discriminate the ECM and DKM concepts in the DST. However, we believe that a thorough analysis of the air-permeability tests performed in different borehole intervals at different heating phases could provide such information, since the ECM and the DKM modeling concept clearly results in different fracture saturation fields. Further analysis of the different modeling concepts will be performed in future studies.

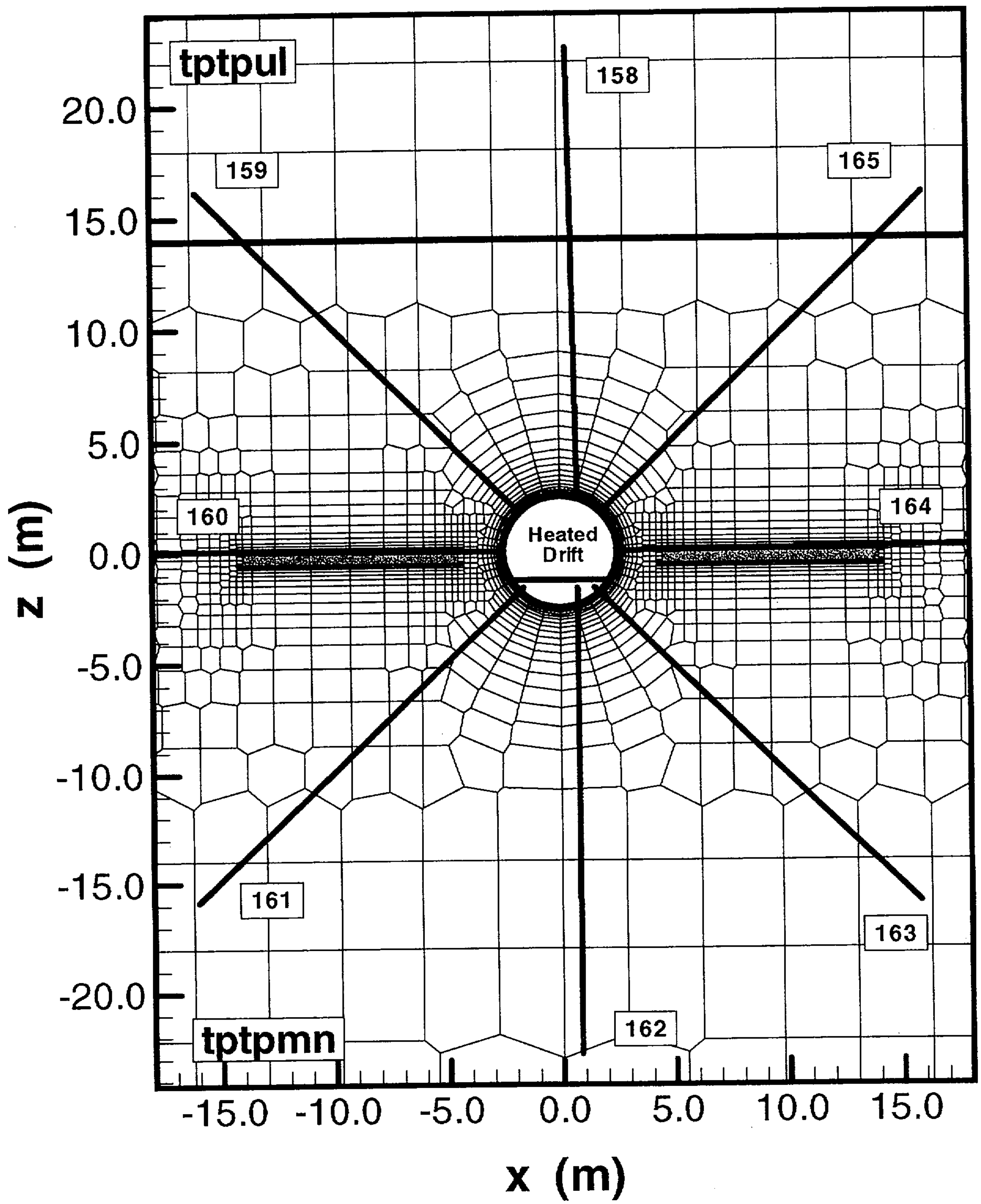
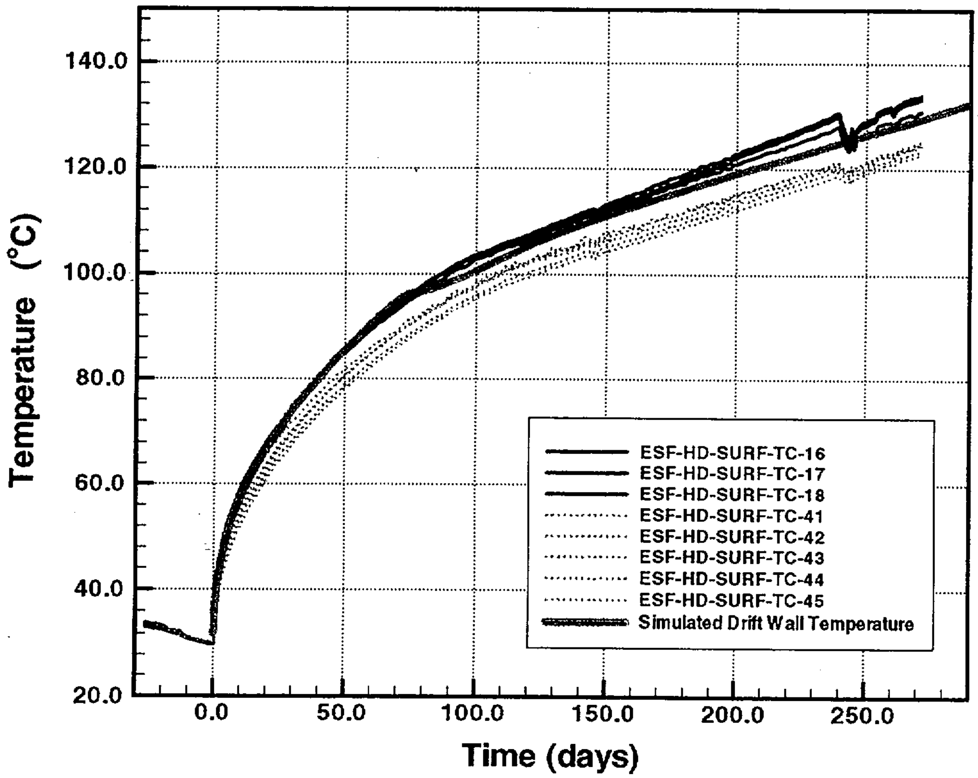


Figure 4.12-1. Close-up view of model grid in a vertical cross section at y = 23 m from the bulkhead with RTD borehole 158 through 164. The blue area indicates location of wing heaters.



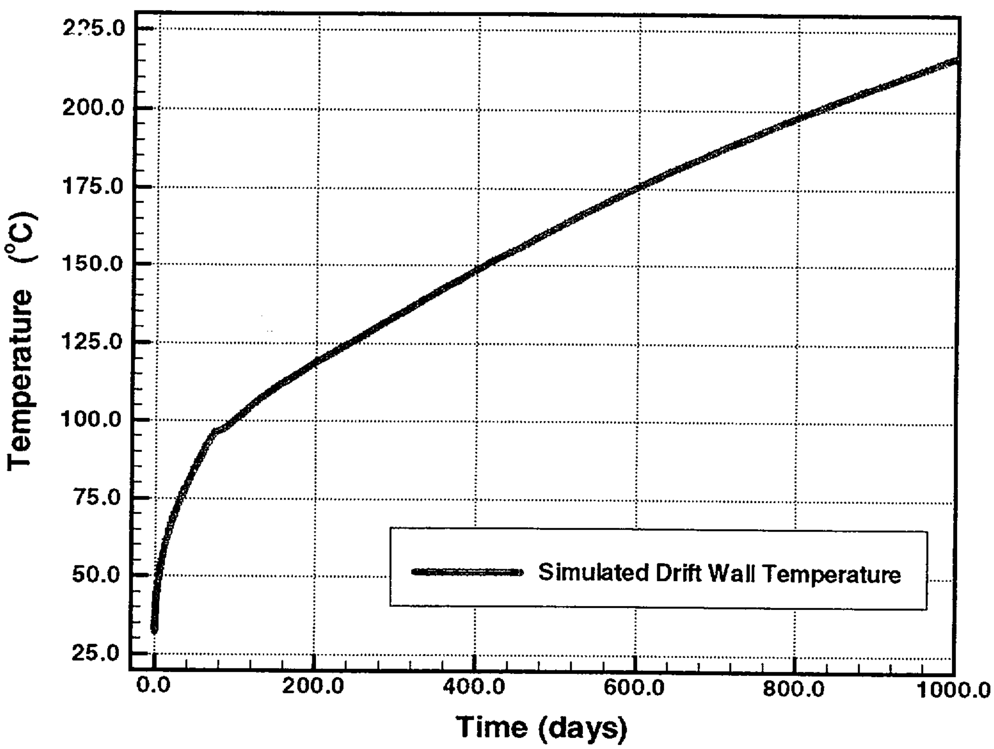


Figure 4.12-2. Measured and simulated temperature evolution at the Heated Drift wall. Measured temperature is shown at two different cross sections along the Heated Drift.

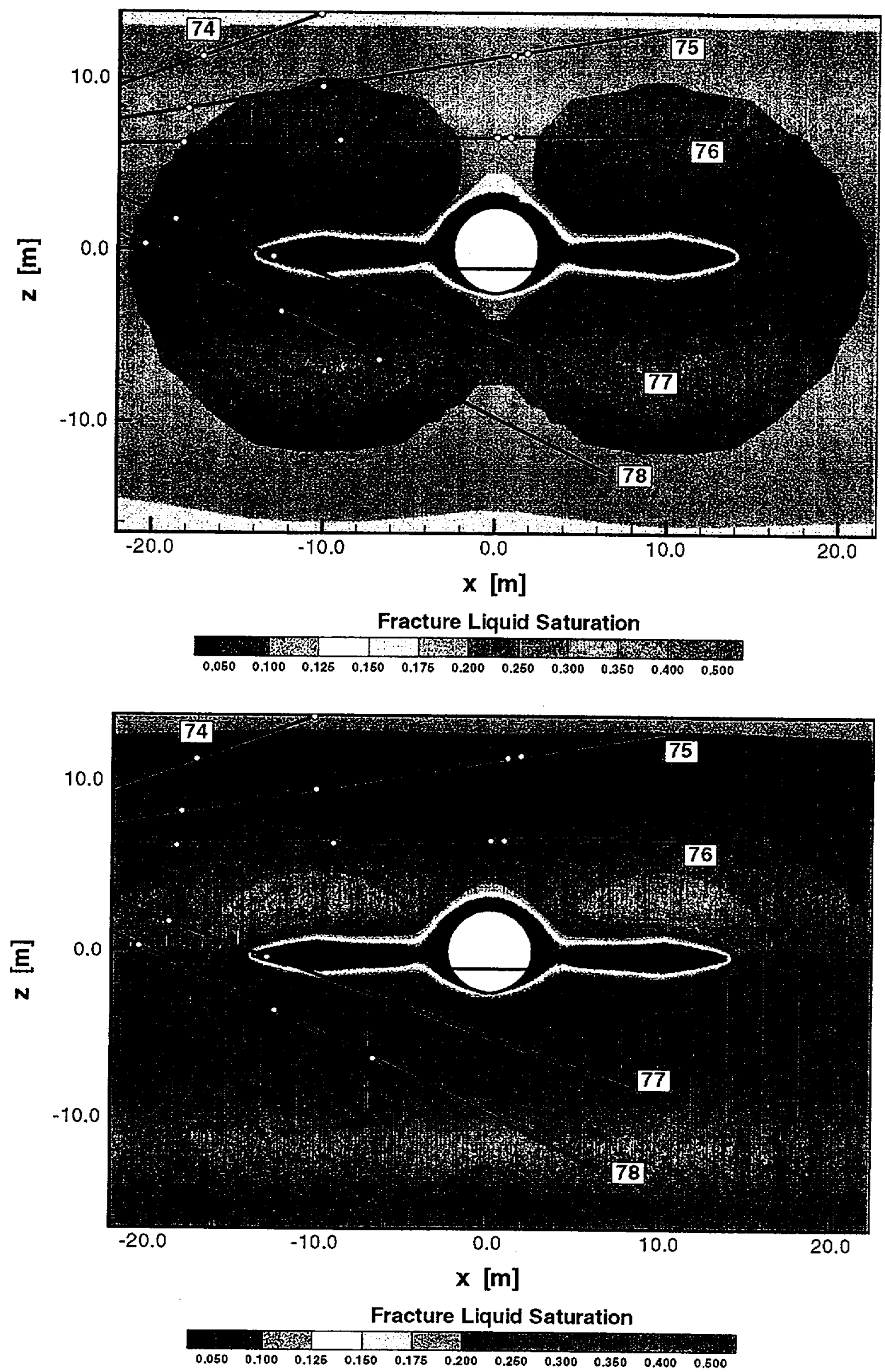


Figure 4.12-3. Fracture liquid saturation at 3 months of heating, using an ECM representation (top) and a DKM representation (bottom). Saturation contours are presented in a vertical cross section with hydrology boreholes 74 through 78,

4.13 THERMAL-CHEMICAL ANALYSIS

The modeling of THC processes for the DST included updates to the chemical model and sensitivity studies on the effects of increased fracture porosity. New gas measurements allowed for some qualitative comparisons to the model results. Refinements of the model included the consideration of CO_2 degassing and transport for full heating and cooling phases of the DST.

Model results show a large region of increased partial pressure of CO_2 (PCO2) beyond the heat pipe zone into areas of near-ambient temperatures. Because of the dissolution of the CO_2 into the aqueous phase the pH of fracture waters in these areas has declined from 8.2 to a minimum of about 6.9. Except for one anomalous water sample, having a pH of 5.5, this agrees favorably with the waters that have been collected from boreholes. The increased PCO2 also agrees qualitatively with measurements from gas samples taken from the hydrology holes. Direct comparisons between model results and measured data is limited by the large packer intervals from which the gas samples are taken, where large spatial gradients in chemistry and temperature are predicted.

The model results indicate that dissolution of cristobalite on fracture walls occurs predominant in the high temperature region of the condensate zone (approximately 90 to 95 degrees C). Most amorphous silica precipitation takes place in an even narrower region at the boiling front and closer to the heater than the center of the cristobalite dissolution region. Calcite dissolution in fractures takes place over a wider area as it is related to the decreased pH due to increased PCO2, and the drainage of lower pH waters into cooler fractures below the heated area. Calcite precipitation is dominant near the drift wall and along the wing heaters owing to its reverse solubility with increasing temperature. The drainage of more dilute condensate waters below the drift is also shown clearly by the chloride concentrations in fracture waters below the drift

Modifications of the "base case" fracture porosity by factors of 5 and 10 were done to evaluate the uncertainty in the THC calculations due to the possibly higher fracture porosities indicated by in-situ tracer testing. While not changing the overall behavior of the system, an increased fracture porosity leads to lower liquid saturations in fractures below the drift and modified water chemistry in the high temperature condensate region. In the most dilute region, chloride concentrations are a little higher for the larger fracture porosity case whereas silica concentrations are significantly higher.

4-14 Heating Plan

The heating phase of the DST was initiated in December 1997 with the wing heaters at 100% of full capacity i.e a total of approximately 143 kW and the canister heaters at 80% of design capacity i.e 6 kW per canister for a total of 54 kW. There were three principal objectives behind the heating plan. These were : a) drift wall temperature not to exceed 200^{0}C; b) a volume of over 10,000 cubic meters of rock to be heated above 100^{0}C; and c) a boiling zone at approximately 95^{0}C will be maintained for approximately 3 years.

Modeling analysis before the start of heating had indicated that with the above power outputs from the heaters, drift wall temperature will reach 200^{0}C in approximately 12 to 14 months. Actual heater power during the first year of heating has averaged approximately 188 kW and some heat loss has been taking place through the bulkhead. The rate of rise of the drift wall temperature has slowed down in recent months with the drift wall temperature at the end of November 1998 at approximately 154^{0}C. The models have been refined based on measured temperatures. Recent modeling indicates that it will take some 20 to 22 months of heating at the current heater power setting for the drift wall temperatures to reach 200^{0}C.

The idea that the heater outputs may be adjusted so that the temperature goals are met sooner, was thoroughly discussed in the October 1998 workshop in Livermore. The consensus was that no adjustment to the heater outputs will be made even though 200^{0}C drift wall temperature may not be attained for another year or so. It was decided that the matter will be reconsidered in 10 to 12 months and adjustments to heater powers will be made if deemed necessary at that time.

The goal of 200^{0}C drift wall temperature was adopted before the start of the heating phase with the expectation that increase in the coefficient of thermal expansion due to phase changes of silica polymorphs may manifest and be observed. However, it is now known that phase changes from cristobalite and trydamite do not occur below 230^{0}C. Thus, the goal of 200^{0}C drift wall temperature was considered unnecessary. Consultation with the repository designers on the other hand indicated that they would like to maintain the goal of 200^{0}C drift wall temperature to observe the stability and integrity of the drift at these elevated temperatures. Maximum drift wall temperature of 200^{0}C, therefore, remains a goal of the DST.

4.15 UPDATING THERMAL TEST STRATEGY

This presentation dealt with the issue of revisiting and ultimately updating the strategy for the DST. Basically, the presentation was divided into three categories: background discussion, the need for a strategy update, and a proposed framework. Background discussion related to the current thermal test strategy as delineated in the report entitled "Updated In Situ Thermal Testing Program Strategy" released in April, 1997. Much of the strategy in that document related to evaluation of specific thermal tests ranging from laboratory testing to a large-scale, long-duration thermal test. Specific details and methodologies such as those corresponding to the 8-year duration of the DST were beyond the scope of this report. Experiences gained from the near completion of the SHT and LBT were also part of the background discussion.

The need for an update to the DST strategy was the second category in this discussion. Factors cited included pre-occupation with the planning, implementation, and early stages of the DST, the comparatively long duration of the test, shortcomings of adhering to the strategy applied to the SHT and LBT, merit of developing a consensus among the TTT, the possibility of the DST becoming a major component of DECOVALEX III, and the benefit of producing a written document with details of the process and its linkage to key program milestones.

The last category dealt with a proposed framework from which to develop an updated strategy to the DST. Components presented included the consideration of various levels of couplings (e.g. one-way, two-way, and full), a process that integrates TTT resources, the interaction with the group responsible for development of near-field process models, and the notion that updating the DST strategy will be an iterative process. Discussion concluded with an agreement to schedule a full-day meeting with PIs, POCs, and technical leads to begin the process of producing a more comprehensive strategy for the DST.

4.16 DRIFT SCALE TEST and DECOVALEX

DECOVALEX is an international consortium of governmental agencies associated with the management/disposal of high level nuclear waste and spent nuclear fuel in Canada, Japan, Finland, France, Spain, Sweden, and the United Kingdom. DECOVALEX stands for **DE**velopment of **CO**upled models and their **VA**lidation against **EX**periments, signifying the overall objective of the consortium. The United States Nuclear Regulatory Commission participated in the first DECOVALEX project, DECOVALEX I, which was from 1992 to 1995. DECOVALEX II, underway since then, is scheduled to be completed in March 1999. Meanwhile, DECOVALEX III is being organized at this time and last summer the Department of Energy applied to join the consortium with the proposal that the Drift Scale Test be a test case for DECOVALEX III.

In November 1998, the consortium invited DOE to join DECOVALEX. The DOE has since decided to participate in DECOVALEX III. The consortium is planning to perform four tasks in DECOVALEX III. These are:

Task 1. Numerical simulation of the FEBEX in-situ THM experiment in Switzerland, proposed by ENRESA, Spain.

Task 2. Numerical simulation of the Drift Scale Test, proposed by the Yucca Mountain Site Characterization Office, DOE, USA.

Task 3. Treatment of coupled THM processes in performance assessment (PA) of Repositories, based on a number of suggestions from DECOVALEX II participants.

Task 4. A forum for outside PA experts to be invited to interact with DECOVALEX III participants to discuss application of THM process models in the performance assessment in other projects.

Organizational meetings for DECOVALEX III are scheduled in January and March, 1999. Actual work is not expected to start until the second half of FY 1999.

11/30/...

ieer

INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

Washington, D.C. office:
6935 Laurel Avenue
Takoma Park, MD 20912
Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

30 November 1998

Dr. Lake Barrett,
Acting Director,
Office of Civilian Radioactive Waste Management
US Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Lake,

Please find enclosed Dr. Yuri Dublyansky's final report prepared for IEER on his examination of fluid inclusions. Copies of five reviews of the draft have been included as appendices to the final report, including the review that you arranged by Joe Whelan, James Paces, Brian Marshall, Zell Peterman, John Stuckless, Leonid Neymark (all of the USGS) and Edwin Roedder (Harvard University). The final report also contains a detailed reply by Dr. Dublyansky to the Whelan et al. review. The final report also contains the detailed exchanges between Dr. Dublyansky and Dr. Diamond. IEER believes that these exchanges exemplify the kind of scientific discourse that is essential to sound research and healthy scientific discourse on what is, admittedly, an exceedingly complex subject.

We were dismayed by the personal remarks, derogatory tone, and factual inaccuracies and misrepresentations in the Whelan et al. review. Furthermore, we found many of the charges made in the review to be illogical and unfounded. If Dr. Dublyansky's motive had been to mislead the public by making "shrewd and nonscientific arguments that seem to be crafted for readers unfamiliar with the specific Yucca Mountain geologic relations," as alleged (see the cover memorandum), why would he have allowed IEER to send you his *draft* report for review? If he were not in fact interested in careful examination of the issues (as is implied in the memorandum) why would he have sent some his samples to an independent researcher (Dr. Larryn Diamond) for examination? Why would he have gone the laboratory of Dr. Robert Bodnar, who is an expert consultant on fluid inclusions to the Congressionally-mandated Nuclear Waste Technical Review Board, for further study and documentation of his samples?

We found other serious problems with the Whelan et al. review related to the data as well. It contains a gross misrepresentation of some of the reviewers' own work that is relevant to the one calculation regarding dating of a calcite sample presented in Dr. Dublyansky's draft report. The review also derides other people's work and implicitly misrepresents both Dr. Dublyansky's draft report and the paper by Grow et al.

Since you arranged for the review, I am requesting you to ask the reviewers to issue a public correction of some of their comments on the draft report and to issue a retraction of their personal remarks on the following specific points:

1. The reviewers misrepresented their own data on the concentration of uranium in calcite (please see page 12 of Dr. Dublyansky's reply). Whether done deliberately or in haste, the effect was to falsely undercut the indicative evidence of relatively young calcite deposits discussed in Dr. Dublyansky's report. The reviewers should correct the public record about the range of values in calcite deposits shown by their own research. They should also note that the one value cited in Dr. Dublyansky's report from his samples is within that range.
2. Whelan et al. state that "the coarse crystal forms of calcite found in the Yucca Mountain unsaturated zone do not occur along steep flowpaths that would be analogous to water films producing flowstones" (point number 14, page 7). This is incorrect. Figure 1 of Dr. Dublyansky's report clearly shows evidence of flow along steep flowpaths. I am enclosing additional photographs showing the same thing for your information. The reviewers' comment is particularly puzzling because, as you can see from the photographs, two of the locations examined by Dr. Dublyansky were marked by Dr. Zell Peterman, one of the reviewers.
3. The reviewers derided an article by Mattson et al. cited by Dr. Dublyansky as "an unknown reference" (point number 19, p. 8). In fact, *Geotimes*, the magazine cited, is published by the American Geological Institute, a non-profit organization that represents scientific societies of geoscientists. Further, the authors of the specific article on Yucca Mountain in question were from Science Applications International Corporation (SAIC), the DOE, and the US Geological Survey. If the authors or the magazine were unknown to the reviewers that was their problem -- and one that could have easily been corrected -- and not a defect in Dr. Dublyansky's work.
4. The reviewers state that, instead of using Mattson et al., Dr. Dublyansky should have referred to Grow et al. on the potential of the Yucca Mountain site for oil and gas deposits (page 8, paragraph 9). Dr. Dublyansky has looked at the Grow et al. paper. The paper presents evidence of hydrocarbon deposits in the general area, though these are not thought to be *commercially* viable. The presence of oil and gas even in small amounts is compatible with Dr. Dublyansky's finding of minor amounts of hydrocarbons in some of the calcite samples. A figure from the Grow et al. paper is included in Dr. Dublyansky's reply to the review. Even if there was a misunderstanding of the draft report as referring to commercial deposits, this is very clearly not the main point of the report or the data. Dr. Dublyansky has clarified the matter in his final report. The reviewers comments imply that the Grow et al. paper contradicts Dr. Dublyansky's data about hydrocarbons, which is clearly incorrect.
5. The reviewers should retract the following personal remarks and innuendoes:
   - The allegations about Dr. Dublyansky's intentions made in the cover memorandum, which are discussed above.
   - The allegation that Dr. Dublyansky was "trying to misrepresent geologic information to those unfamiliar with the Yucca Mountain area" by citing the Paintbrush fault when he possibly intended to invoke the Bow Ridge Fault

(point 10, page 4 of the review). Dr. Dublyansky re-asserts that he did intend to refer to the Paintbrush fault. The reviewers and Dr. Dublyansky may disagree on his interpretation, but the allegation of attempted misrepresentation was an incorrect speculation by the reviewers.

- In view of the discussion above of the Mattson et al. and the Grow et al. papers, the reviewers should withdraw the comment that "Dr. Dublyansky seems to know little about this [hydrocarbons in relation to the study of Yucca Mountain] subject." In addition, their comment that his failure to review the Grow et al. paper before "may represent another example of the selective use of information" (point 19, p. 8) is inappropriate. It is quite normal for reviewers to refer researchers to additional papers or contrary evidence. It is not at all normal for them to speculate on the motives of the researchers. This remark is especially unwarranted inasmuch as the reviewers themselves were unaware of an article in a readily-available magazine that contains the work of researchers from institutions centrally involved in investigating Yucca Mountain, including the USGS, where all but one of the reviewers currently work.

If the reviewers other than Dr. Whelan are not responsible for the comments in the cover memorandum, then they should publicly disassociate themselves from them.

I know that the subject of fluid inclusions is one on which are widely differing views that are strongly held. Indeed, that is one of the main reasons that I sent the draft report to you for review. Scientific disagreements are common and, in an area as complex as the geology of Yucca Mountain, they are to be expected. But these disagreements can and should be addressed through respectful discussion of the issues. For instance, despite our different points of view, you and I have had a fruitful exchange of views. I really appreciate the openness with which you have approached our discussions and the scientific integrity that has led you to propose joint sampling and study of fluid inclusions in which Dr. Dublyansky would be among the principal researchers.

We owe electricity ratepayers, taxpayers, and future generations the benefit of honest, open, and respectful scientific discourse. The review by Whelan et al., because of its *ad hominem* remarks, seems aimed at stifling debate. This is a disservice to the public. I sent you the report for review, trusting that we would get a response that would do justice to the gravity of the task at hand. In that spirit, I look forward to hearing from you and from the reviewers.

Yours sincerely

Arjun Makhijani, Ph.D.
President